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Water Quality Monitoring and Modeling Workshop

Proceedings

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PROCEEDINGS: WATER QUALITY MONITORING AND MODELING WORKSHOP
Edited by William M. Crosswhite, USDA, and James Meek, EPA; Natural Resource Economics Division; Economics Research Service; U.S. Department of Agriculture; Washington, D.C. 20250; June 1981. Staff Report ADES810506.

ABSTRACT

Water quality monitoring and evaluation is a major feature of the Rural Clean Water Program and will likely be included in related programs in the future. The Proceedings examine the state-of-the-arts in water quality monitoring and modeling, the needs of user groups and the relationship between modeling and monitoring. The linkage between economic and water quality monitoring, modeling and evaluation is explored. A systems approach, utilizing models and monitoring, is presented as a useful tool in designing water quality control projects, determining pollution abatement effects, quantifying the impacts of alternative strategies and management systems and evaluating the effectiveness of pollution control measures.

Key Words: Water quality, Models, Monitoring, Conservation practices, Hydrology, Sediment, Pesticides, Nutrients, Salinity

ACKNOWLEDGMENTS

The workshop was cooperatively sponsored by the U.S. Department of Agriculture and the U.S. Environmental Protection Agency.

PREFACE

The purpose of the workshop was to develop an understanding of water quality and economic monitoring and modeling needs for program and project planning, implementation and evaluation. Specific objectives were to:

1. Identify information needs of user groups to guide water quality and economic monitoring and modeling activities.

2. Acquaint users with the planning and evaluation capabilities and limitations of monitoring information and water quality models.

3. Encourage use of monitoring and modeling techniques and information to increase program effectiveness.

4. Develop capability to support the planning, implementation, and evaluation activities of water quality programs.

The document is primarily of interest to those responsible for soil and water conservation projects who need to assess project impacts on water quality. It provides state-of-the-art material and should be supplemented by contacting attendees of the workshop for additional information on specific applications.

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INTRODUCTION - USDA

Larry Libby, Coordinator, Land, Water, Air, and Solid Waste
U.S. Department of Agriculture

The purpose of this workshop is to bring together in one room those who understand and build models with those who may use the results. For some reason these two categories seem to be largely mutually exclusive, though perhaps not entirely. Our goal here is to get greater cross-pollination among individuals from several agencies for the long run benefit of all. More specifically our objectives are:

(1) to identify water quality and economic information needs to guide modeling efforts;

(2) to foster improved application of monitoring and modeling techniques;

(3) to acquaint users with the capabilities and limitations of various monitoring and modeling systems;

(4) to develop the capability to support planning and evaluation activities to water quality programs

(5) to improve the decision process of government by improving our ability to develop information on consequences of various actions.

We "softies"--the nonquantitative types--are here to find out if sophisticated models are really worth anything beyond their intrinsic beauty and mathematical elegance. We are interested in the usefulness of these formal abstractions. I am confident that both the modelers and the users will benefit significantly from the discussions. The modelers need to face the "so what" questions of models. Policy types and other users need the added discipline of thinking systematically in comparing decision options.

Systematic impact analysis is becoming increasingly important in resource policy. The Resources Planning Act (RPA), the Soil and Water Resources Conservation Act (RCA), the National Forest Management Act (NFMA), and the Rural Clean Water Program (RCWP) are cases in point. Each of these contains a specific requirement that careful impact analyses be conducted in designing and evaluating policy. We have an increasing obligation to demonstrate the consequences of actions and measure the performance of programs.

This conference will foster communication among builders and users of models that can be sustained over time. We must build on this conference to suggest additional steps to be taken to really improve our overall effect.

I'd like to briefly trace the background for this conference. The idea for the workshop grew out of our work on the Model Implementation Program (MIP) undertaken as part of the 208 program. There are seven MIP projects around the nation designed to examine various ways of focusing government attention on the water quality problems. We recognize that evaluation of this MIP experiment is necessary. Yet in the original design of the MIP, evaluation has not been of high priority.

Those of us on the MIP evaluation subcommittee discovered that we had relatively little information to go on in making comparisons. We then discovered a number of models being developed and used in the MIP areas and in other settings around the country. Each of us had scattered experience with certain physical and economic models but no one had a very complete overall picture of monitoring and modeling activities underway or how those activities might serve the purposes of policy analysis for the MIP.

It was this practical need that led to early planning for the workshop. An additional impetus came from the current efforts to implement RCA. The RCA process involves the analysis of various soil and water problems in six categories including water quality, food and fiber production, water supply, fish and wildlife habitat, energy conservation, and flood control. We are developing formal models to analyze policy options for dealing with problems within each of those six categories. RCA has adapted several physical and economic models in an analytical system. We hope that this conference may add additional insights to their work.

INTRODUCTION - EPA

Paul Heitzenrader, Water Planning Division
Environmental Protection Agency

The purpose of these workshops for EPA, a joint sponsor, is to describe EPA's research role pertaining to monitoring and modeling and to provide a status report of EPA's efforts.

EPA's efforts stem from its legislative mandate. The Water Pollution Control Act Amendments of 1972 was really the first effort to address the problem of nonpoint source pollution in agriculture and forestry. In particular, Section 104 and 105 of those amendments directed the agency to provide research on methods to prevent, reduce, and eliminate agricultural pollution. This work was to be conducted in cooperation with the Secretary of Agriculture. The Act also set forth the requirements for 208 areawide planning, and contains specific references to controlling nonpoint source pollution.

The 1977 amendments reiterated and strengthened the rural and agricultural provisions of the 1972 act and, more importantly, set forth Section 208(j). Section 208(j) makes available cost-sharing monies to be administered by USDA for agricultural and forestry BMPs. EPA evaluates BMPs to insure identification of the most cost-effective practices to enhance water quality. The effective implementation of BMPs and management systems will insure the best use of the RCWP funds when allocated to improve our waters.

We have been involved in monitoring and modeling activities since 1972. It was determined that the agency could not monitor and sample every stream in the country and needed a modeling effort to identify and assess agricultural nonpoint source problems and to delineate more critical areas. A conscious decision was made that it isn't sufficient just to build elegant models that give nice mathematical answers but rather to develop models with site specific physical and chemical data.

Another conscious decision was made to build upon existing hydrologic and sediment models. While this has saved considerable money, it has caused some concern that the approach has been too narrow and the approach is being evaluated to give more weight to transport processes.

Late in the 1974-75 period it was recognized that dealing only with the nonpoint source loads in a watershed is not completely adequate. Rather, it is necessary to link water quality to what is happening on the land, what is being applied, what is being produced, and what is leaving the land area.

A field evaluation program has been developed with the purpose of testing and evaluating the tools EPA generated, as well as those generated by others. Such a program concentrated our resources to improve the evaluation of models, the testing of BMPs, and the selection of BMPs for a particular watershed. The field evaluation program began with the Iowa Four Mile project. What is learned in Iowa will be used in the RCWP and MIP projects to improve these programs. In the field evaluation program, we expect to look at both the physical modeling and monitoring as well as economic models. It is important to examine what is happening on the land in particular fields, the processes of transporting the pollutants, and the impacts on water quality.

The EPA-sponsored project on data collection and storage systems has reached a point where we have developed expertise in modeling runoff from highways. We are now integrating into these programs with the instream water quality processes.

We plan to become more involved through field evaluation programs in a comprehensive integration of land use and instream processes to show the impact of man's activities on water quality. A nonpoint source water quality Center of Excellence will be established at our Athens Laboratory to relate what is happening on the field and the impact this has on water quality in the stream, including the economic aspects. We expect to continue refinement not only of our models but of other models through the field evaluation program in Iowa.

WHAT ARE THE MONITORING AND EVALUATION NEEDS IN RCWP?

RURAL CLEAN WATER PROGRAM (RCWP) EVALUATION

The November 1, 1978, rules and regulations implementing RCWP established monitoring and evaluation as an integral component of program management. Specifically, section 634.50(a)(1) states, "Representative RCWP project areas will be selected to evaluate the improvement in water quality in the project area and to make projections on a nationwide basis. Water quality monitoring, evaluation, and analysis will be conducted to evaluate the overall cost and effectiveness of projects and BMPs to provide information on the impact of the program on improved water quality and for general RCWP program management."

SCS views water quality monitoring and evaluation as an essential component of the management process and defines evaluation as the process of management which systematically analyzes the extent to which RCWP achieves its objective improved water quality. Evaluation is divided into three general categories according to their purposes. These categories are:

Comprehensive Evaluations - Evaluations designed to assess the impact and effectiveness of representative projects and/or specific RCWP project components.

General Evaluations - Evaluations designed to assess BMP application progress and to document related changes in water quality attributed to an RCWP project.

Program Evaluations - Evaluations designed to determine (a) the extent of which the RCWP is meeting the objectives, (b) the effect of RCWP on its participants as opposed to the rest of society, and (c) the relationship of costs to benefits.

RURAL CLEAN WATER PROGRAM MONITORING

Water Quality Monitoring and Models in RCWP - The kinds of nonpoint source (NPS) pollution from agricultural activities are very complex phenomena in themselves and become ever more complicated because they are very often interrelated and all based on rather complex hydrologic and hydrogeologic processes. Consequently, it becomes obvious that a systems approach, utilizing models and monitoring, is one of the best tools for assessing pollution from agricultural land and for quantifying its changes under various alternative management systems.

This "systems approach" will play a key role in the evaluation of RCWP. This role includes the following:

(1) RCWP is designed to "target" in on critical NPS areas. Monitoring and modeling will help provide a sound basis for identification of these critical areas.

(2) Each management agency must assure an adequate level of participation in the program at the project level. Education of potential participants, through use of model outputs, will aid in reaching this level.

(3) Our philosophical makeup as water quality managers has included the belief that water quality standards for nonpoint sources can and should be used as management tools for the formulation and reevaluation of policies and programs, not for enforcement. Within this framework, failure to achieve water quality standards after implementation of RCWP in a project area will require successive iterative steps to modify the program. To do so effectively it is important that monitoring procedures be technically and politically sound. In this regard, the following recommendations are put forth:

   (a) Monitoring should not be limited to the receiving water. Failure to achieve water quality standards may be due to one or both of the following reasons: BMPs were effectively implemented, and/or BMPs were implemented but are insufficient. It is important to be able to make the distinction.

   (b) The technical arguments put forth to demonstrate the need for RCWP modification must be more rigorous than has often occurred in the past for point discharges. Monitoring programs must be based on a recognition of the complexity and variability of aquatic ecosystems.

   (c) Modeling efforts must recognize the limits of our knowledge. First, the relationship between land use activities, terrain characteristics, nonpoint pollution runoff, and the resulting water quality is not clearly understood, either quantitatively or qualitatively. Secondly, the effectiveness of various BMPs in reducing the NPS pollutants is in many cases not accurately known. Thirdly, water quality standards are sometimes insufficient for describing the impact of nonpoint pollution (e.g., erosion).

   (d) Monitoring water quality in all cases is impractical and may not provide much evidence of the effectivenss of RCWP in the short run. This has important implications for research particularly in modeling. We must not let incomplete or misinterpreted measurements distort our views of the effectiveness of RCWP. We need to develop new ways, or refine existing methods to measure water quality improvement. A better understanding of when to measure, what to measure, and how to interpret those measurements is needed.

(4) Monitoring and modeling in RCWP will improve our ability to design and apply BMPs and to predict with greater certainty their total effect on water quality.

There are a whole host of other questions that SCS, as a user agency, will consider. Some we might call institutional issues, other economic. For example, the rural community in general, observes

a more direct relationship between modification of the operations of farms, the cost to do business, and delivery mechanisms of a program than the relationship between BMP application and water quality. How can the complexities of the natural system best be conveyed to the farmer? Do monitoring and modeling have a role in this conveyance system?

The answers to these and many other such questions create the need for a great deal of research study, and innovative thinking. If we can be optomistic that technical problems can be solved, so can the organizational and financial arrangements.

FUTURE CONSIDERATIONS

The systems (monitoring and modeling) being developed for evaluating NPS pollution are not to be considered an end in themselves, but rather as a first step toward the development of user oriented comprehensive systems. Comprehension will not be measured by numbers of variables or complexity. Simplicity and user acceptance will continue to be the criteria for system improvements and refinements.

Data are not sufficient for testing all facets of models. Initial models will help identify critical areas, evaluate programs, but in addition, identify areas in which research is needed. Some well-planned data collection programs must be developed to adequately test model concepts. These efforts coupled with RCWP will provide a common focal point for a sound water (quantity and quality) management program.

WHAT ARE THE ASCS USER NEEDS?

William Sallee, ASCS, USDA

BMP SELECTION

At the local level the county ASC committee, in consultation with the ACP Development Group, must annually identify and select best management practices with which to solve the most critical conservation and pollution problems. In addition, the information developed in the 208 planning effort is another tool which these groups may use in this decision process. We are looking for this workshop to provide yet other tools.

IDENTIFYING CRITICAL AREAS

The ASC county committees are encouraged to screen applications for cost-sharing assistance and to approve those with the most immediate need to solve critical conservation and pollution problems. This is a challenge for ACS county committees, to select applications for Federal funding each year to solve the most critical conservation and water quality problems.

NEW APPROACHES

The ASC county committeemen are knowledgeable of problems on the various farms in their county. However, if there are other information techniques which can assist in the decision process, the ASCS is interested in learning of and implementing these new techniques. This workshop may bring us some new ideas, as well as identify other approaches to be developed in the future by land grant universities, agricultural research groups, the Environmental Protection Agency, and others.

EXTENT OF PRACTICES

There have been questions on the design of practices from some ASCS State program specialists as a result of feedback from county ACP development groups and farmer participants. Some of the practices being cost shared under the ACP may be over-designed for the purpose of solving conservation or pollution problems in the most effective manner.

EVALUATION OF ACP PROJECTS

In the MIP projects, ASCS, through the ACP, has put in \$1.4 million in 1978 and \$1.5 million thus far in 1979. We, of course, are interested in information that might be helpful in selecting the right practices, the most cost effective practices in project efforts, and in evaluating the water quality accomplishments.

Also, in the special ACP water quality projects funded from the national reserve, ASCS has allocated \$4.3 million thus far in 1979 to that effort. We are interested in information from this workshop that will help these projects to do the best job possible in improving water quality and in evaluating the results of the projects.

A Cornell University/EPA Research project had used a model that shows for certain plots that terraces could be built wider apart. The rationale for this was that a strip of grass could serve in place of a terrace to solve some of the erosion problems in a more cost effective manner. Is it true that modeling can assist in this effort? If so, ASCS and the SCS, who has technical responsibility for most practices cost shared under the ACP, should be interested in such information.

We are looking for ideas. We want help from this workshop in order to relate monitoring, modeling, and evaluation methods and theories to ongoing project efforts and in advising farmers who are or will be implementing land treatment measures under programs to conserve and improve our Nation's soil and water resources.

BACKGROUND ON ASCS WATER QUALITY PROJECTS

ASCS has been involved in conservation cost-sharing programs and, indirectly, water quality improvement for some 40 years since the Agricultural Conservation Program (ACP) was authorized in 1936. Beginning about 1969 the Nation became concerned about the quality of our environment, including water quality. Since 1970, the ACP has directed additional funds toward helping with improving water quality by adding pollution abatement practices to the National Practice List, particularly practices for animal waste control.

The ACP is carried out by cooperating USDA agencies at the national, State, and local levels. These agencies serve on the ACP Development Committees and provide support such as technical services (through SCS and FS), education (through the Extension Service), loans (through FmHA), and research. In recent years EPA has been added as an advisory member on water quality. Other groups such as conservation districts, State water quality agencies, and those interested in conservation and pollution abatement participate in ACP Development at the State and local levels. The ASCS in recent years has directed the ACP toward special projects through funding from a national or State reserve. The special project concept helped USDA and EPA in 1978 in developing and bringing to reality the MIP concept. ASCS reserved \$1.5 million in 1978 funds at the national level for assisting in MIP project areas in the installation of land treatment measures.

The targeting of the seven MIP projects selected for the program represents an acceleration and coordination of USDA and EPA efforts in accomplishing water quality improvement and in measuring and evaluating the results of installing treatment measures.

Under the 1979 ACP a national reserve of $10 million was established for special project efforts. The national reserve is used to fund the seven MIP projects and ten small farmer projects started by ASCS in 1978. The 1979 national reserve had a water quality special project emphasis. In early April the Secretary and the Administrator of ASCS announced the approval and funding of 21 projects with program emphasis on water quality improvement and 18 special projects which include Small Family Farm Assistance. ASCS is providing providing $1.2 million of ACP funding of conservation measures to be carried out in 12 of these projects. Several give emphasis to solving water quality problems.

On July 17, the Administrator of ASCS and EPA's Assistant Administrator for Research and Development entered into an agreement whereby ASCS through ACP funding will assist farmers in the installation of conservation measures in the EPA Water Quality Research Project in Tama County, Iowa. Prior to 1979, three years of base data has been collected. Various models will be used in selecting BMPs to be installed in different areas of the Four Mile Creek project area.

In addition to the national reserve, $10 million of the ACP State allocation was earmarked for special projects approved by the ASC State committees. Based on informal information from the State offices, a high percent of these special projects, some 280, will be for solving water quality problems.

In recent years the ACP has been funded at about the $190 million level. To give an idea of the extent of accomplishments that might be expected from such funding, let us look briefly at the following data.

Practices Meeting ACP Program Objectives	Dollars	Percent of Total
(a) Prevention of soil loss from wind and water	$88,000,000	51.5
(b) Solution to water conservation problems	34,800,000	20.0
(c) Solution to water quality problems	20,000,000	12.0
(d) Conservation of soil and water through forestry	2,200,000	1.0
(e) Conservation of wildlife habitat	800,000	0.5
(f) Local practices (Special practices) 1/	25,000,000	15.0
		100.0

1/ Many of these related to solving water quality problems.

DEFINING CRITICAL AREAS

At Stanford University there is a computer science colloquialism that says, "If you don't know what your program is supposed to do, you'd better not start writing it."

Today in agricultural nonpoint pollution there is some terminology that has been misunderstood and misused! One example is that of "critical areas."

A critical area has been defined by some to mean an area of substantial soil loss that is impacting a stream or reservoir. Others have added that a critical area is one that can be treated with the efficient expenditure of public monies. That our ultimate goal is to improve water quality through the wise and prudent use of taxpayer's monies. We have discovered in the Model Implementation Program (MIP) that some high soil loss areas may require a mrather substantial amount of public monies in cost-share incentives programs. And that some of our "Prime Agricultural Lands" -- those areas which normally have fewer erosion hazards--are highly fertile soils with larger amounts of nutrients (phosphates and nitrates) attached to the clay and silt particles. And that these pollutants can often be controlled rather easily with a change in the cultural management of the crop. Changes that can be brought about with educational programs and less expensive cost-share practices.... It's not easy to identify "critical areas." We must first have an understanding of its meaning.

We must know whether the term "critical areas" means "soil loss," "sediment transported to a stream," "nutrients," or the "relative costs of implementing best management practices."

GULLY EROSION

Another aspect of the problem is that we presently evaluate only the impacts for sheet erosion. Research from 10,000 plot years of test data has confirmed the effectiveness of the Universal Soil Loss Equation in estimating sheet erosion, but we have yet to find an effective way of estimating the progression rates of gully erosion -- so we ignore it in our evaluation techniques. The evaluation of gully erosion is important, and the Indiana Heartland MIP is developing its own methology.

The control of gully erosion often requires the use of long term structural practices such as sediment basins, diversions, terraces, grassed waterways, and grade stabilization structures. These practices require significant engineering design and installation assistance by skilled technicians. This type of assistance has been the backbone of our conservation programs which has given us public recognition. It is often the first step in the development of complete water management plans for solving soil erosion problems on farms. This is not a single practice approach-it is a problem solving approach. We need, therefore, to evaluate systems of practices rather than a single BMP.

We are finding that some erosion control practices are more effective during the large storm events than others. If the large storms cause the most damage as far as degrading water quality then our programs in the future should respond to these needs. In the MIP, biologists are studying the various aquatic communities in our streams to see if they are more susceptible or vulnerable to nonpoint source pollutants during certain seasons of the year. Hopefully, they may also give us insight into the impact of various storm events.

WATER QUALITY DATA

The problems associated with gathering and imputing accurate data have been avoided. Obviously there are many needed improvements in this field. The need for more comprehensive evaluation techniques has been pointed out. Computer modeling offers the greatest potential for evaluation water quality programs.

Many cry for more monitoring programs to gather base data for agriculture. The "baseline data" as far as agriculture is concerned is an erroneous term. Ever since man first poked a stick in the ground to plant his first seed, agriculture began to change. Today, agriculture is a dynamic process. It is rapidly changing. And even if you were to monitor a stream for twenty years you would not have baseline data for agriculture. The circumstances would be different. No two storm events will ever occur under the same conditions. The crops would vary. The vegetative cover will be in different stages of growth. The soil conditions may be different. Cultural practices vary and the land use will also change from time to time. There are just too many variables and the technique of gathering monitoring data is too slow.

Monitoring data can best be utilized, however, to fine-tune a computer modeling program. To measure the results of single storm events and compare the results with the computer's output of the same programmed event. And then let's expand the computer's program to analyze hypothetical annual events. This is comprehensive analysis.

WHAT ARE THE FS USER NEEDS?

Jim Eggleston, FS, USDA

The Forest Service is involved in many activities, both within our own agency and in cooperative programs with other State and Federal agencies. These programs can, and do, cause water pollution problems if not properly implemented. We consider sediment as the primary nonpoint source of pollution, but there are other nonpoint source pollutants that come from forested lands.

MONITORING

The Forest Servich has traditionally been a user of water quality data. However, as we entered into a monitoring program for water quality we found that limited information was available, so, by necessity, we became a collector of water quality and quantity information as well as a user. With the passage of PL 92-500 and its amendments, we did get involved quite heavily in monitoring programs in all nine of our Forest Service regions. Some of those efforts are continuing today. We expected to be able to monitor a project for 3 or 4 years before an activity was implemented, then go back and monitor for another 3 or 4 years after implementation to come up with answers to causes and effects of activities on pollution. Instead, we found that there were many frustrations involved. Some of the things we found were quite discouraging. We found that even after 8 years experience in monitoring, there were still significant differences of opinion as to how monitoring should best be carried out. Should an intensive amount of sampling be done over a very short period of time, i.e., hourly for 2 or 3 days and daily for the remainder of that month, or should it be spread out over the year to get seasonal representations?

There is still much discussion as to how this should best be done. The statistical reliability of monitoring, particularly on a short-term basis, is high questionable. You cannot measure highly variable pollutants such as sediment that are naturally induced through weather events, and come up with statistically reliable results in a short period of time.

We found it was easy to plan for both sample collection and sample and data analysis, but for various reasons it was often difficult to carry out these functions. Those same weather conditions that caused an event we wanted to sample often prohibited someone from getting into the field to take the samples. Equipment that worked fine in the laboratory often did not work consistently under the adverse outdoor conditions with which we had to contend. Unless the job of sample collection and analysis is specifically assigned to a person and paid for by a particular project, other job priorities often preempt this task. Sampling is expensive in terms of time, equipment, sample analysis, and other work not done. We often did not have the person-power or the dollars to do the job properly.

In spite of all the drawbacks, we did find some good things about monitoring. A big part of the problem we encountered was that long term data, 15 years or longer, was not available for reference purposes. This was This was particularly true of the small streams that we we were dealing with--the first, second, and third order headwater streams of our mountainous lands, where many of our activities take place. We recognize that monitoring of undisturbed watersheds to establish base line water quality data is essential for future reference.

We found that is an activity had great enough effect on water quality to be picked up in this imprecise monitoring effort, the situation was serious. However, even though the magnitude of change was great enough to be detected it usually was not possible to quanfify the change with any degree of reliability. Just as important was the fact that negative results, i.e., not being able to detect a change, generally meant that the activity did not have a significant effect on water quality.

One of the most important things we found was that the precision of the results needed varies with the magnitude and importance of the expected impacts of the project activities. Monitoring for a project in a municipal watershed would be much more intensive than for a similar type of project in a remote location. Another factor to be considered in determining the intensity of monitoring for a given project is the expected cost of monitoring in relation to the cost of the project itself.

MODELING

We also found there ia another way of determining the impacts of project activities on water quality, and that is through modeling, however, one of the major requirements for modeling is a good data base. We did take a look at modeling, and learned that there are also at least two distinct levels of precision of results, just as in monitoring. One level of precision is that needed for research purposes where a minimum of 90 percent reliability is required. The other level is that required for operational purposes where the level of reliability can be as low as 60 to 65 percent. A comparison of some elements common to both types of modeling will help clarify why different levels of precision are acceptable.

	Research needs	Operational needs
Area	Small, site specific; easier to to isolate variables.	Large physiographic areas; much more difficult to isolate or measure variables.
Data Requirements	Many variables; willing to measure each one repeatedly, for several years.	Often must use data on hand or readily available without new measurements. Generally use fewer variables.
Timeliness	Study period may be many months to years--allow time to improve reliability.	Managers often have to make decisions within days or weeks.
Objective	To prove or disprove theories or postulates--requires a high degree of reliability.	To manage land and resources, often under Congressional mandate, according to program objectives.
Cost	High cost per unit of output, but willing to pay to accomplish objectives and reliability.	Cost per unit must necessarily be much lower or program objectives cannot be met.

We recognize the potential of modeling to meet operational water quality inforamtion needs--particularly with regard to erosion and sediment. Modeling offers two primary benefits-a saving in time and a saving of money, while yielding generally acceptable results for localized situations. There are, however, several criteria that models must meet to be more responsive to Forest Service needs. These criteria are:

1. A model must provide valid results for a relatively large geographic/physiographic area;

2. It must utilize readily available or easily measured data;

3. It must be able to account for differences in outputs in relation to various management practices;

4. It must take variables such as soils, vegetation, slopes, landforms, and precipitation (both rainfall and snowmelt) into account;

5. It must include streambank and gully erosion as well as sheet and rill erosion;

6. It must specify delivery ratios for different pollutants under various conditions; and

7. The results must be compatible with the results of the models for other geographic/physiographic areas in terms of outputs and accuracy.

The various laws and acts that Larry talked about require that we be able to prepare a consistent inventory of erosion and sedimentation problem areas--and of problem area rehabilitation. This will require that as many as possible of the above criteria be incorporated in the modeling and/or monitoring process.

THE FOREST SERVICE POSITION ON MONITORING AND MODELING

It can be summarized as follows:

1. Short term project monitoring--it is usually very expensive and doesn't have much pay off.

2. Long term base line monitoring--is essential to establish as reference, but it is still expensive. Must be extremely careful in the selection of streams for long term monitoring.

3. Modeling--has great potential for operational purposes, but the criteria mentioned earlier need to be met.

We are currently using both techniques, monitoring and modeling, depending on the individual situation.

However, there are some other considerations we need to think about. One of these is the reasoning behind the best management practices (BMPs) concept. The reasoning is that if development is going to take place, and it must--we must have farming, ranching, and silvicultural operations--then if we use BMPs society will be willing to accept the remaining portion of sediment or other activity. If this concept can be accepted, then there is no real need for monitoring or modeling of water quality on specific projects, except to fill in pages to see that practices being used are indeed BMPs.

Another consideration is the need for process oriented research to develop and evaluate new practices that might become BMPs. Through this type of research amounts, timing, and effects of pollution can be compared for different practices to determine which are truly BMPs. If hard data is required on pollutant production, then it can be obtained from this type of research on small, carefully controlled areas and the results can be extrapolated to project implementation areas.

The last point to be considered is the need to look at and revise where needed State water quality standards. Current standards generally reflect point source pollution in terms that can be controlled through regulations. We feel that standards are needed that reflect the natural sources

and variability of nonpoint source pollutants--pollutants that cannot be easily monitored or controlled because they do not have either a single or common source.

The last point to be considered is the need to look at and revise where needed State water quality standards. Current standards generally reflect point source pollution in terms that can be controlled through regulations. We feel that standards are needed that reflect the natural sources of variability of nonpoint source pollutants--pollutants that cannot be easily monitored or controlled because they do not have either a single or common source.

We do recognize the need for quantified water quality data, either from monitoring or modeling. If the considerations just mentioned can be incorporated into our various programs, the need for monitoring or modeling for water quality will be reduced to a minimum and more emphasis can be placed on administration of the programs themselves. We would much rather see the programs drive the monitoring and modeling effort rather vice versa.

WHAT IS RCA?

The Soil and Water Resources Conservation Act of 1977 (RCA) calls for an appraisal of the status and condition of the Nation's soil and water resources and for the development of a USDA program that addresses problems identified through the appraisal.

Many programs, over the 118 years since USDA was established, have addressed resource problems. Most, however, have come into existence since the mid 1930's. At the present time, there are over 28 resource related programs administered by USDA agencies. These range from the technical assistance programs of the Soil Conservation Service (SCS), to research and education by the Science and Education Administration (SEA) and the Economics, Statistics, and Cooperatives Service (ESCS), to cost sharing by the Agricultural Stabilization and Conservation Service (ASCS), and to loans for resource conservation and development by the Farmers Home Administration (FmHA).

RCA calls for us to pause and take a look at the water and land resource problems facing the Nation, to review the existing programs, and to determine their applicability and effectiveness. It also calls for the President to recommend any needed changes in program content and structure.

Because of the complexity of this task, we have actually taken more than a pause. Along with many people from the USDA agencies that have land and water conservation programs, representatives from the Office of Management and Budget (OMB) and the Council on Environmental Quality (CEQ) have been working on RCA activities. Some of the major questions that have been addressed are:

1. What is the continued need for UDSA programs in the area of soil and water conservation and management?
2. What are the high priority items that need to be addressed?
3. Where are the needs for soil and water conservation?
4. How much is needed?
5. What are the most cost effective ways of meeting these needs?
6. Who will receive the benefits and who will bear the cost?

The main purpose of the inventory, analysis, and modeling carried out for RCA has been to determine whether or not something should be installed.

DATA SOURCES

There are several basic data sources being used in the RCA analysis. These include a National Resource Inventory (NRI) conducted by SCS in 1977. This inventory provided data on land use, erosion, extent of land by capability class and subclass, and other natural resource characteristics. Other major sources of data include the more than 1,100 SCS county soil surveys completed between 1961 and 1977. Another major source of data has been the 1975 National Water Assessment of the Water Resources Council. I have named only three of the major sources. As an early part of the RCA analysis, ESCS carried out an activity known as LAWREMS (Land and Water Resource Economics Modeling System). The LAWREMS report is more than 1 1/2 inches thick and identifies data sources and models that have potential for analyzing soil and water conservation programs.

Data collection and model development are not cheap. Development costs alone on many national models have run into the millions of dollars. For this reason, and because of the short time available to complete the 1980 RCA report, we have emphasized the use of existing models whenever possible. Two major national models being used were developed outside USDA: the National Interregional Linear Programming Model at the Center for Agricultural and Rural Development at Iowa State University (ISU) and a National Water Quality Framework Model developed by Resources for the Future (RFF).

AWARENESS OF NEED AND PARTICIPATION BY FARMERS

An area that has received little attention in past modeling efforts, both within and outside USDA, has been the question of accounting for landusers' awareness of conservation problems, their acceptance of a need to address these problems, and rates of their participation in USDA land and water resource conservation programs.

Stanford Research Institute (SRI) has long been a national leader in the area of modeling for decision analysis. Under a contract with the Soil Conservation Service, SRI is developing a decision model that incorporates the physical and economic information available from inventory and other modeling efforts such as the ISU model. We all know, for instance, that we are not going to change water quality unless something changes physically on the land. We have to install and maintain some conservation measures or best management practices. Something has to change and someone has to make a decision to cause it to change. The landuser who controls the decisions on land that he or she owns or operates will or will not install some conservation on the land. What we are trying to model are the incentives, institutions, and behavioral motivations that influence the landuser's decision. We feel that this effort has great potential in analyzing alternative strategies for the implementation of USDA land and water conservation programs.

PROJECTIONS

We have updated most of the coefficients for the ISU linear programming model. These include cost-return data from the 1977 NRI. The ISU model was also updated with new demand projections that ESCS developed for the years 2000 and 2030. These projections were developed

for three future scenarios. These were for low, baseline, and high demand.

We can't say much about the impact of soil and water conservation on future productivity before saying something about the impacts of erosion on crop yields.

Baseline projections show that the demands on the resource base in this country are going to be large. For this scenario, we are using the Series II Commerce Department population projections. These projections call for a domestic population of around 300 million by 2030, approximately 84 or 85 million more than U.S. population today. We're looking at a projection in 2030, of per capita disposable income increasing from about $4,100 to around $16,000 (in 1972 dollars). We're looking at export demands that, for many commodities, are approximately double the present levels. You can imagine how much pressure there is going to be on the resource base in terms of the amount of land needed to produce this food and fiber, and the water quality problems that could be encountered if these demands are met without proper concern for the environment and future condition of the Nation's resources.

There is also likely to be a continued and even accelerated trend in bringing additional land into cultivation to meet these demands. When prices for farm products rose dramatically in 1973-74, many acres of land that had been used for forest, rangeland, and pasture were converted to cropland use. This happened particularly in the south where high prices for soybeans stimulated increased production. In running the models for the RCA analysis, we will vary the level of erosion reduction to determine the least-cost combination of land use and treatment needed to meet projected commodity demands.

EROSION RATES AND POLLUTANT CONCENTRATIONS

The RFF water quality framework model is being used to assess the impact of present and projected erosion rates on the sediment, phosphorus, nitrogen, and BOD components of water quality. This model links pollution generating activities, both point and nonpoint, to a water quality network of 304 rivers, 175 lakes and reservoirs, and 37 bays. As a result, the water quality network model can stimulate pollutant concentrations for individual water bodies, and these can be compared to monitored concentration estimates.

While we feel that we have the best data base that has ever existed relative to the present and potential condition of the Nation's land and water base, there are still many areas where reliable data are hard to find. For example, data establishing the relationships between land use, insecticide and herbicide application, and the delivery and transport of these chemicals are scarce and tenuous at best. Information on the factors that influence landusers' participation in conservation programs and application is almost nonexistent. In many areas, the extent and severity of productivity, water quality, water conservation, and other problems have not been fully quantified.

In short, future soil and water conservation programs will be developed as past programs were formulated. That is with a mixture of good information, poor information, and no information. Decisions will be made based on the best information available. Decisionmaking will be based on a blend of quantified data developed by monitoring and modeling efforts, best judgements from experience and observation, and a "feel" for what is "right."

Those of us who take part in modeling and monitoring efforts have an opportunity to broaden the base of knowledge and improve the quality of information that decision makers use in developing and implementing programs that contribute to the efficient management and use of the Nation's soil and water resources.

WHAT ARE THE MARYLAND USER NEEDS?

Ken McElroy, Maryland Department of Natural Resources

ESTABLISHING CRITICAL AREAS

The State of Maryland has established a procedure for selection of critical areas making a first-cut statewide. Our agricultural program provides that each soil conservation district conduct a similar procedure in determining the critical areas within its district boundaries.

Our 208 program only addressed the control of sediment and animal waste. The program has yet to deal with nutrients or pesticides. Some of these substances, however, will be controlled when BMPs are applied. The 208 program did not deal with nutrients or pesticides because we didn't have enough data to warrant a control program.

The first set of criteria we used to select the critical areas was land use. There were three criteria used for the first cut. First, which segments have agricultural and forestry land use that is equal to or greater than 85 percent of the total land for that segment.

The second criteria was to take the areas identified above and select those areas with at least 40 percent in agricultural land use.

The third criteria was to narrow down the areas to those where at least 50 percent of the agricultural land use was on critical soil types. We were able to screen out roughly 40 to 60 percent of the segments based on these three criteria.

Next, we looked at sediment and determined a value score by using five water use categories. These were finfish, shellfish, water supply, water contract recreation, and wildlife. For each of those categories we assigned a score between one and three based on whether or not we thought that the use was particularly important for that particular segment. For example, the criteria for finfish would be a three if it was a major nursery, spawning area, rare or endangered species, or trout reproduction area; a two if it was a minor nursery, spawning area, or stock stream and had the potential for year round trout or biologically unique species; and we gave it a one if it was a minor nursery or spawning area for only one or two species or for commerically insignificant species. We then scored the 134 watersheds and produced a map showing the impact of sediment.

We then developed a procedure to assign a sediment severity score, i.e., 0, 10, 30, or 50. The parameter we used was turbitity, for which we gave a score of 50 for frequent violations, 30 for an occasional violation, 10 for no violation, and 0 for unaffected area. This gave us a geographical distribution of whether the turbitity standard was a problem.

Using a similar process, we looked at bacteria and assigned water uses a value score based on whether bacteria was a problem in the segment. We also considered the distribution of rainfall as contributing to the ~~impact~~ of bacteria pollution on the shellfish, especially in areas around the Chesapeake Bay where there is a very considerable impact. Considering bodies, we again scored, if we had frequent violations, 50; occasional, 30; no violations, 10; and unaffected, 0.

We then produced a map of manure equivalence where we called one manure equivalent the amount of manure one would expect from a full grown dairy animal. We also did this for domestic animals and for wildlife.

The net result of all this was a first cut of potential critical areas for the State. The screening process yielded 14 segments that we deemed to be the critical areas out of a total of 134.

Some questions that keep coming up as we carry on this program are: What are the benefits of water quality? How do we quantify them? What are the economic impacts of carrying out management practices on the farm? We have used 208 funds to finance inventory work by soil conservation districts. We believe this will give us the data we need as input to most of the models that were available for use in the agricultural runoff areas. Farmers frequently want to know what runs off their land and how does this runoff affect water quality. In Maryland we have been able to pursue a program where the districts are working on providing technical assistance for management practices on the land.

There is a serious need to consider monitoring water quality at the local level. County commissioners are very much in touch with the farmers, and they are very much in touch with the agricultural community. The more monitoring we do at the local level, the more quickly i will be communicated to people in the districts and people in the county governments. This will allow the locals to start work on the problem more quickly.

The monitoring and modeling work needs to be very selective and it must be effectively communicated. As these various studies are finished, they need to be precise and presented quickly and effectively to people who make the political decisions on how to fund these programs and how much funding should go into them.

MODEL AND MONITORING WORK SESSIONS

The workshop sessions were organized around four categories of modeling and monitoring activities including:

1. Loading Functions and Field Scale Models

   a. CREAMS Model - W. G. Knisel, SEA-AR, Arizona

      The model reported in this paper consists of three major components: hydrology, erosion/sedimentation, and chemistry. The hydrology component estimates runoff volume and peak rates, evapotranspiration, soil water content, and percolation, all on a daily basis. The erosion component estimates erosion and sediment yield including particle size distribution at the edge of the field. The chemistry component includes a plant nutrient element and a pesticide element. Stormloads and average concentrations of absorbed and dissolved chemicals are estimated in the runoff, sediment, and percolation fractions.

   b. Answers Model - Larry Huggins, Purdue University

      Reference: Beasley, D.B., E.J. Monke, and L.F. Huggins, 1977. ANSWERS: A Model For Watershed Planning, Agri. Exp. Sta. J., Paper No. 7038. Purdue University, West Lafayette, Indiana. 34 pp.

   c. ARM/NPS - Lee Mulkay, EPA, Athens

      Reference: Donigian, Jr., A. S., and N. H. Crawford. Modeling Nonpoint Pollution from the Land Surface, U.S. EPA. Environmental Research Laboratory, Athens, Ga. July, 1976. 279 pages.

2. Watershed and Basin Water Quality Models

   a. Hydrologic Simulation Program - Fortran - Norm Crawford, Hydro-Comp, California

      Reference: Johanson, R.C.; J.C. Imhoff and H.H. Davis, User's Manual for the Hydrologic Simulation Program-Fortran (HSPF), Environmental Research Laboratory, Athens, GA 30613.

   b. Model of Watershed Response - Daryl B. Simons and Ruh-Ming Li, Colorado State University

      This paper provides an overview of watershed modeling efforts at Colorado State University. All of the models are based on physical significance that considers the principles of conservation of mass, momentum and energy. Various geographic levels of models have been developed for practical application.

c. Iowa Watershed Model - Thomas E. Crowley, III and Gene Whalen
University of Iowa

The model is designed to perform most calculations for the user. Almost any watershed configuration can be handled. Features include: spatial and temporal rainfall variation, flood and sediment hydrographs, cross sections automatically calculated, use of natural channel or geometric shapes, different roughness coefficients and more than one storm can be simulated on the watershed at different locations at different times.

3. Economic Models

a. Horner, G. L. and D. J. Dudek, "Analytical System for the Evaluation of Land Use and Water Quality Policy Impacts Upon Irrigated Agriculture" in Dan Yaron and C. S. Tapiero, Editors, Operations Research in Agriculture and Water Resources, North Holland Publishing Company, Amsterdam and New York, 1980, pp. 525-536.

b. Iowa Cedar Model - Klaus Alt, ERS, USDA

The chosen objective of the LP model is minimization of the monetary production costs of the required level of field crop production. The restraints include land availability limits on cropping patterns due to agronomic considerations, proportion of crop output expected from the study area and alternative environmental restraints. A large number of production alternatives are specified, differentiated by such characteristics as tillage methods, soil conservation methods, and crop rotations. Model vectors include such activities as input purchases, insecticide application, terrace construction, and transfer vectors.

c. Evaluation of Water Quality - Russell L. Gum and Eric B. Oswald
ERS, USDA

Models for several types of evaluation are discussed. Cost effectiveness models search for the least cost solution to meet predetermined standards such as water quality standards, limits on erosion, etc. Benefit-cost analyses search maximum dollar benefit per dollar of cost solutions for alternative projects that are considered. Environmental-economic tradeoff analyses search for a set of solutions that maximize economic benefits for alternative levels of environmental quality.

4. Water Quality Monitoring

a. Monitoring for Project Evaluation - Frank Humenik, North Carolina State University

Reference: See the paper on Water Quality Monitoring in following section.

b. National Water Data System - Paul Kapinos, USGS

The conceptual model of the national network defines three levels of information that correspond to the amount of detail needed for planning. Level I is a base-level of information for national and regional planning and assessment, and provides the foundation for the more detailed and precise activities. Information at this level is uniform nationwide and should be sufficient for a general estimate of the water-resources quantity and quality in any given place at any given time. Level II consists of data for water-resources planning and assessment within a subregion, commonly a major stream basin. Information at this level is non-uniform nationwide and responds to needs within each subregion. Level III comprises data for water-resources operation and management at the local level. Information at this level responds to operational needs as they arise, and is consequently nonuniform from area to area.

c. Economic Aspects - Lee Christensen, ERS, USDA

A partial list of questions related to economic issues surrounding water quality monitoring include:

1) What are the parameters for an economic evalution? What physical data is needed? For alternative levels of quality measured there are different levels of costs at the farm.

2) Is the same monitoring approach valid for both farms and watersheds?

3) What are sensitive economic indicators to measure success for achieving water quality improvement? Do small changes in water quality improvement come at a large cost in farm production and income?

4) What about a combined monitoring and modeling approach? Modeling can identify alternative land treatment options. Economic analysis may suggest use of modeling in the selection of land treatment options.

Each workgroup was assigned the task of presenting information on models and monitoring activities in each category. Speakers focused on the capabilities and limitations of the models, information provided for project planning and evaluation and the type and content of training needed by program and project managers.

Synoposis of Work Sessions

Session chairmen were assigned the task of providing a synopsis of the information presented in the four work sessions. Information on specific monitoring and modeling activities was presented to workgroups to examine the capabilities and limitations of models and monitoring activities and identify research and training needs.

LOADING FUNCTIONS AND FIELD SCALE MODELS

Jesse Lunin, SEA-AR, USDA

Several field scale models are available or are being developed for use in assessing nonpoint pollution. How to deal with the profusion of presently existing models is one of our major problems mainly because these models have not been either adequately tested or validated. This problem was highlighted in 1978 at a Section 208 (PL 92-500) Conference held at Cornell University by representatives from a number of 208 areas in their presentations on the use of various models. Most of these models had not been adequately tested or validated.

Information Provided by Field Scale Models

Field scale models provide estimates of annual pollutant loadings or concentrations resulting from a specific storm. The models also provide an assessment of the nonpoint source pollution potential that can be used to identify critical areas and evaluate Best Management Practices (BMP's). Models can be used to or project long term effects of alternative land uses and practices, as well as to assess the effect of specific storm events. The usefulness of results depends on the questions being asked and the types of problems to be solved.

Field scale models can be used to interface with stream models for comprehensive water quality analyses. They are best used to assess the degree of water quality improvement, estimate the degree of pollution abatement achieved, and predict changes in pollutant concentration from individual as well as combinations of BMP's.

How simple or complex should a model be? This will depend on the purpose of the model and on whether it is a field or basin scale model. Some users like to use a model as simple as the Universal Soil Loss Equation, whereas others complain that most models are not sufficiently comprehensive to cover all situations. The question of model complexity needs to be resolved from the standpoint of model development and validation. How much actual data are needed to test and evaluate a particular model and for how many locations?

Dr. L. Huggins, Purdue University, states that models can be useful in assessing cost-sharing levels. Since no universal model exists, an array of models is needed in order for the appropriate model to be selected to solve a specific problem. This requires that the problem be accurately defined before the appropriate model can be selected. Once this is done, a model can then be selected and used to identify and assess critical source areas and the results will be useful for determining priorities for cost sharing assistance.

Capabilities and Limitations

It is desirable to achieve a level of sophistication in modeling such that models can be developed and verified for use at several locations without further adaptation. Some important questions that need answering are: How widely can you transfer a model developed for a specific location? Can you transfer or use a model only at other locations within the same

geographic area? If the model is broad enough, can it be transferred and used in other geographic areas? These are important questions. When making water quality assessments, it is important to keep in mind that agriculture is dynamic--not static. Modeling activities and efforts are trying to evaluate a system that is gradually changing. Modelers have to recognize that model users are generally not knowledgeable concerning a model's capabilities and very often are not technically qualified to select an appropriate model. How should the user go about making this decision?

To whom does the user go for help? Again, no universal model is available. However, is there a general concept that can be developed to provide guidance to users in selecting models? Very often it may not be cost effective to model an entire project area. It may be desirable to apply a field model to a selected field scale area and then extrapolate these results in order to evaluate an entire project area. It may be desirable to go one step further and to extrapolate data to a physiographic area.

Most models are so complex that we need a consultant to assist in applying and interpreting model results. How far can we go in simplification of a model and still maintain a satisfactory level of credability? Can field scale models really be simplified? Even for physically based models, some data base is needed for fine tuning. Very often data are not available to satisfactorily evaluate modeling of efforts.

Several times at this workshop, speakers stated that technical people generally accept the idea that models are credible and provide useful information. However, users and decision makers do not understand models, and they often question their usefulness. What alternatives do we have? It is impossible to monitor all the streams nationwide to evaluate nonpoint source pollution. We will have to depend on models and it is incumbent upon the scientific community to develop models that can achieve a reasonable level of credibility with the public.

The subject of accuracy versus precision in monitoring has been discussed, and it is an important issue in model development. How well can we predict, what level of accuracy can be achieved and what level of accuracy are we willing to accept? Have most models been tested, and do we actually know how well they can predict?

Research Needs

There seems to be general agreement that research is needed on the process-oriented aspects of modeling to strengthen various components of our models. For example, a useful nitrogen model component requires researchers to have a knowledge of the complete nitrogen cycle. The weakest link in the nitrogen cycle is the process of denitrification. Numerous people have worked on this process and still the researchers lack a good understanding of it.

Thousands of available pesticide compounds can be broken up into discrete classes. We need to know the various processes that determine the fate of these compounds. We must delineate losses from volatilization and photodegradation of these pesticides and know their solubilities. We have to quantify how much is intercepted by the plant canopy and how much actually reaches the soil. Although these data cannot be obtained for all compounds, perhaps this information can be categorized for a signficant number of classes of pesticides.

Erosion is a major problem. Although we have made signficant progress in evaluating rill and interrill erosion, evaluating gully erosion is still a problem. Although there has been considerable research on the mechanics of gully erosion, little progress has been made in developing predictive relationships for losses from gullies. As a result, this is a weakness in some of the models.

We need better assessments of particle size distribution in eroded sediments. Information on total sediment load is not sufficiently detailed. From the standpoint of chemical pollutants a stream containing a very light sediment load might be carrying a considerable chemical load because of its highly collidal content. Some rivers in Oklahoma are running red because of their suspended colloidal material. If sediment is measured in terms of parts per million or milligrams per liters, the data might not look very serious, but those streams can carry significant amounts of nutrients, pesticides, metals and other pollutants attached to a small amount of suspended colloidal material. Information is needed to improve our understanding of the role of sediment transport and delivery mechanisms. We need to examine cause and effect relationships. That is a rather broad assignment but a very signficant one.

Models can be used for developing and evaluating new BMPs. Through sensivity analyses, models can be used as a research tool to determine the most significant parameters and to provide better quidelines for developing good management practices. Model testing and refinement must be improved to increase their sensivity so as to improve our understanding of transport phenomena.

Greater emphasis should be given to developing remote sensing information as a data base. Remote sensing data on land use are used as inputs into some models but more can be done. This data source is also being developed to acquire and access soil moisture data. Other potential data sources should be explored. Currently, considerable data are stored in various systems that are available for use in model application. These sources need to be inventoried.

We need to increase our data base through reseach monitoring. Research monitoring involves the design or lay out of a watershed to provide monitoring data for use in developing and testing our models. All kinds of data are available in existing data systems, but most data sets are inadequate for testing models. Data from several locations and geographic areas are needed to evaluate a model's universe. More interdisciplinary research is needed to develop better models.

Modeling should be used to guide the improvement our monitoring efforts and to make our monitoring more cost-effective. Sensivity analyses can be used to identify important parameters to be monitored. Modeling results can provide for improved recommendations, for example, on the number of samples, sampling frequency and a rationale for site selection.

We need a national center of excellence on modeling to provide an unbiased assessment of models. This group could make recommendation on models that are the best models for particular types of problems. They could take the lead in developing a technology transfer effort. Basically, because of the profusion of existing models, a group is needed to provide guidelines for users in selecting models and identifying models that have been validated.

We need to evaluate pollution impacts. While our group discussed field scale models that look at the edge of the field, it is also necessary to know which pollutants reach a stream and what their fate is as they move downstream. At what point does pollution become significant and where within a watershed does this occur?

Training Needs

The level of competence required by users, such as program and project managers, must be taken into consideration. Modeling is a relatively new process with very little appreciation by water quality project planners We know little about the types of available training or the likely effectiveness of such training programs.

Information should be provided on the availability and capability of various models, their potential uses and interpretation of their results. This all comes under the heading of technology transfer. There have to be linkages between the scientist developing the model, the action agencies using it, and the planners using the final product and interpreting the results. Workshops should be developed at various levels. For example, workshops for modelers are needed to develop and evaluate models. Workshops for managers would be helpful to train them on the use of the models, interpretation of their results and to recognition of their capabilities and limitations.

WATERSHED AND BASIN WATER QUALITY MODELS

Jim Meek, EPA

A number of models for stream systems are available and discussions during the session focused on three of those models--the Hydrocomp model, the Colorado State model and the Iowa model. Discussions covered the risk we take in using models to represent a stream and the difficulty in obtaining solutions. Much of the preceeding presentation on field-scale models also applies to this session. Additional observations and commentary are provided below.

Information Provided by Watershed/Basin Models

These models replicate the physical processes of a stream system and allow us to better understand how the natural processes interact. From these systems or models we can make qualitative assessments of likely changes and adjust our actions in response to the impacts brought about by changing conditions.

The models are a tool for comparing alternatives only after they have been validated as representing the real stream system. They are extremely useful in sensitivity analysis in determining the factors or elements in the system that are most influenced or sensitive to change, i.e., weather and land uses.

Models provide frequency curves for comparing the damage or social costs when water quality is degraded or a beneficial use is impaired.

The use of models allows us to monitor water quality change and provides a better means for evaluating the effectiveness of the BMPs.

Capabilities and Limitations

Models are very fast and provide quick calculations. Typically, the calculations would take months if done by hand but can be done in minutes in models. The outputs may not be precise, but they are the best we have now.

Models developed early in a project can be useful in project formulation. It is particularly useful to determine what data you need to develop through monitoring activities. Too often a wide range of parameters is sampled at great cost only to find that some critically needed data were not sampled. Besides reducing costs, the simulation of data provides a chance to rethink our approach in a project especially when the model produces inconsistent results. Such a "blow up" of a model signals that there are problems with our assumptions or data. Again, the model exercise allows for corrections to be made before the mistakes are made in the field thereby saving considerable program costs.

While there are many advantages in using models, modeling is not simple or easy. Considerable thought and effort is required first to develop the model that simulates your system. The next step is to concentrate on interpreting the data coming from the model. This is not a simple or easy task.

Research Needed

To meet the needs of the user, we should think of setting up a modeling clearing house where individuals could go with their needs, examine models already developed that would fit their situation and, if necessary, be assisted

with model modifications. This would also provide a place where the individual could receive long term training (3 months) or what we might term "hands on experience" rather than just being talked at. We also need to look at:

- the short and long term data needs of models
- coupling of the physical models with management models
- coupling of the physical models with economic models
- improving the evaluation of the accuracy and sensitivity of the models
- ways to improve estimates of model costs
- the use of films to close the communication gap between user and modeler

<u>Transfer of Modeling Capability to User</u>

As mentioned previously, we need more "hands on opportunity" for the user--a chance to study examples and to see what the models can do for the problem. It appears that without this type of experience we will be unable to close the gap between the skeptics, users too shy to ask questions and the model developers.

Models are not appropriate for all situations. However, where they are appropriate and are not being used, because of a lack of understanding or modeling experience, we are missing opportunities to improve the effectiveness of programs. There is frustration between the user and the modeler in trying to close the communication gap.

ECONOMIC MODELS

Roy M. Gray, SCS, USDA

Jerry Horner presented the modeling work that is being conducted in the San Joaquin Basin, California, on the pollution impacts of irrigated agriculture, return flows and salinity. The model divides the San Joaquin Valley into some 200 mini-regions. The linear programming model requires large amounts of production and resource information when applied to an area that has been divided into small segments.

The second presentation by Dr. Klaus Alt outlined his work on the Iowa Cedar River Basin. The study was a combined analysis of erosion, sedimentation and economic impacts of sedimentation in Carsville Reservoir located on the Iowa River. The study examined the impacts of alternative practices and levels of erosion reduction on farm costs and agricultural production.

Russ Gum presented economic models for studying public participation in the decision process and developing a better understanding of what is taking place. This is important if we are going to have continued public support for water quality activities. The public has to take part and is often asked to support us on the faith that we know what is happening. Modelers need to inform the public on developments in their work so the public can see what is taking place and understand what is happening.

Frank Humenik presented information on the statistical aspects of water quality monitoring. He talked about Type 1 and 2 errors. A Type 1 error is the probability of accepting a false hypothesis while a Type 2 error is the probability of rejecting a true hypothesis. Russ Gum added to the list two more that are just as important. A number 3 error is the probability of formulating a trivial hypothesis. A number 4 error involves all of the above but carried out too late to provide useful answers to decision makers. Here are some of the things that those involved in economic modeling of environmental problems need to keep in mind.

(1) Modelers need physical data to link with economic data. There must be close interaction and communication between physical scientists, economists and modelers in doing this work.

(2) Team members must learn to communicate by speaking the same language. Interdisciplinary work will never be achieved without effective communication and understanding of what it is we are trying to do together.

(3) Researchers must identify and establish physical relationships for use by managers in selecting activites to be carried out and for better understanding the impact these measures are likely to have.

(4) Researchers need to identify the relationship between the physical measures, costs and other economic consequences of carrying them out, both in the long term and short term.

These concerns are tied in with people's perception of equity. Activities that pay for themselves in the short run are perceived to be equitable since the producers carrying them out receive the benefits. However, if activities don't pay for themselves in the short run, maybe the public should consider the need to provide some help. This is an equity question. Other equity questions involve offsite benefits, on-site costs and questions of the impacts across broad geographic regions. Is one area of the country going to be unfavorably impacted, if a uniform standard is set at the national level? An activity in one area may be low cost and meeting the standards may be relatively easy. In another area these same activities may be expensive and meeting the standards may be very difficult. These economic considerations should be included in our modeling work in terms of the impacts of the activities that we are doing. Another issue that arises is the difficulty of estimating the dollar value of physical changes. As economists we have troubles enough putting dollar values and numbers on commodities that are valued by market transactions without the added task of valuing nonmarket goods.

The tendency of economists to move too far and fast tends to create credibility problems in modeling. This problem is most apparent when we try to put a dollar value on goods and services for which there is no readily available market. There are problems with combining physical variables into a composite value such as an "environmental index." But this information would be useful. These are some of the issues that should be worked on but we need to recognize that going too fast can cause credibility problems for us.

Models tend to grow after addressing a particular question and selecting the appropriate data. As useful information is developed, the modeler wishes for a little more data and time to answer evolving questions. The model is allowed to expand and develop. The most important question, however, is: What are the priorities?

We need to ask ourselves upon completion of the work and examination of our numbers if the information we are providing is useful and the numbers we are developing make sense. We can get a decimal place off and the numbers may look pretty wild or we can get the decimal point in the right place and the numbers in the right ball park and they can make sense.

Economic modelers as well as hydrogolists and engineers and other physical scientists face some of the same problems. The user must have a good perspective of the person doing the modeling. The user must be convinced that modeling being done is, at least, objective. The work and results may be wrong, but at least the work is accepted if it is objective. The modeler is not going to be able to convince the user he is doing an acceptable job if the work is subjective.

If the user is looking for an advocate, he ought to hire a lawyer. The chairman of my graduate committee pointed out that a scientist cannot be an analyst and advocate at the same time. There is a delicate relationship that has to be established, and it has to be built on trust and objectivity. These are two key considerations for people who are working in the area of economic modeling.

WATER QUALITY MONITORING

Jim Eggleston, FS, USDA

Both sessions were well attended and the participants contributed freely to the discussions. While most discussion was oriented towards the questions of "what monitoring and modeling can and can't do," much philosophy was also included. Discussion points have been summarized for presentation.

-- The Model Implementation Program (MIP) was set up as a test and forerunner for the Rural Clean Water Program (RCWP). We should wait until we see the results of monitoring on these MIP projects before we spend a lot of time and money designing monitoring programs for the RCWP or other programs, especially in relation to water quality from specific projects.

-- Monitoring can be based on water quality, land uses, or best management practices (BMPs). Land treatment may provide valuable soil and water conservation even though water quality differences may be very subtle, and changes may not even be detected by the monitoring system selected for evaluation of the project.

-- No combination of BMPs will overcome poor land uses.

-- More pre-treatment data is probably available on land use and practices than on water quality. This data needs to be looked at in relation to similar practices in different locations--are they as effective in one place in comparison to another? In other words, just what are best management practices?

-- The USDA is not speaking to the total needs of the producer with their current programs. Economic models should be used to help develop and analyze alternatives of management and use to better meet all needs. It must be recognized that the "best" alternative from the producer's standpoint may not be the "best" alternative for water quality when total costs of production, total income, effects on water quality, both onsite and off-site, and other costs and benefits to society are analyzed. We (USDA) need to be able to tell the producer how much more, or less, production he will get if he installs certain practices, not just what the practice will do for "society."

-- Water quality improvement can generally be best obtained by concentrating treatments on small, critical areas. Water quality improvement can best be detected by intensive monitoring of these same areas. However, monitoring and evaluation should be tied to a National scheme rather than to individual sites, and final evalution emphasis should be on total impacts of a "system of BMPs" rather than on individual practices or individual farm units. This will probably require that monitoring data from small areas, where variables have been carefully controlled, be used in conjunction with models to predict overall results. This will be necessary because the sum of the parts is not equal to the whole in terms of effects of BMPs on water quality.

-- Monitoring is often thought of in terms of enforcement, while modeling is thought of in terms of projections. However, monitoring is generally not an end unto itself, and modeling must often be used to extrapolate information from one site to another appropriate site. A combination of monitoring and modeling is often a better evaluation tool than either one separately and can be used to analyze alternatives and identify tradeoffs.

Before application, models do require calibration or verification for the particular geographic/physiographic/economic regions in which modelers are interested.

-- What is nonpoint source pollution? Water quality is important primarily in relation to existing or potential uses for that water. Natural sources must be recognized, and, if possible, separated from accelerated or man-caused pollution. We must be careful to monitor only those parameters that are currently critical or have a good chance of becoming critical. Monitoring techniques and intensity must be carefully selected to meet the objectives for monitoring and/or evaluation at that site.

-- Are State water quality standards realistic in relation to nonpoint source pollutants? Standards should recognize receiving waters (stream, lake, estuary, ocean) and the natural variability of nonpoint source pollutants (length of time pollutant may be at critical level, variability due to natural runoff process, time of year pollutant is normally in the water, etc.) This will probably require a number of "sets" of standards for any given State.

-- Nonpoint source pollution is a major factor in water quality, but natural sources and quantities must be recognized. Water will carry sediment. If we reduce erosion and keep that sediment on the land, the clean stream will pick up sediment from previous deposits, or from stream banks, and will continue to carry a given amount of sediment until new gradients and channels have been established. Much sediment now being carried in streams, especially in the South, is a result of historical land abuse. Significant improvement in land use and in reduction of nonpoint source pollutants has been made. However, cost-benefit relationships may drastically limit the degree of improvement in the future.

-- Water quality data is available from several sources. Quality control of data is the data collectors job, but quality varies from collector to collector, and even within a given collector agency. It is the user's responsibility to find out the quality of the data he intends to use is, and to analyze it and report his findings appropriately. User beware!

-- The USDA and EPA must educate the general public on the overall potential and limitations of water quality improvement programs. To date, much of the driving force for water quality improvement has been from "environmentalists", not the general public, and their goals have sometimes been unrealistic.

-- Several programs have been "sold" to the Congress, and the public, on the basis of improving water quality--but to date we have not had great success in being able to prove that water quality is improving. We should continue these programs using "common-sense" practices that we know will benefit soil resource conservation, as a minimum, then try to determine the effects on water quality through selective monitoring or modeling. If there are no quantifiable water quality results, let's say so,--and stop pushing the programs on the basis of improving water quality. Let's push them on the basis of soil resource conservation and maintenance of soil productivity.

-- Do we know enough to sit down and prepare a monitoring/modeling scheme to be able to evaluate National programs such as RCWP to meet the needs of USDA/EPA? It is the consensus of the group, that we do have the knowledge. But we must design the monitoring, analysis, and evaluation system before monitoring begins, and all parts of the evaluation must be considered as a package. We must also realize that raw data must be analyzed before it becomes useful information. What we're trying to say is "Don't undertake vast projects with half-vast ideas!"

-- In the final analysis, a better solution to the pollution problem is found in the Bible. II Chronicles 7:14 states: "If my people, which are called by my name, shall humble themselves, and pray, and seek my face, and turn from their wicked ways, then will I hear from heaven, and will forgive their sin, and heal their land."

CONCLUSIONS--WHERE WE GO FROM HERE

Larry Libby and Dennie Burns, USDA
Paul Heitzenrater, EPA

The individual group reports are excellent statements of the key conclusions and needs for the future. However, a rephrasing in several concluding statements might help to clarify the choices we face in how we might proceed.

Conclusion No. 1 - We need to recognize that people have resource problems--governments have agencies and laws. The problems themselves may not break down neatly into specific agency programs or pieces of legislation or disciplines. We must seek ways to combine skills and programs to deal with real resource problems that occur in the countryside. We should avoid parallel efforts in policy implementation. We discovered recently, for example, that our efforts to implement the President's Water Policy initatives were becoming an exercise in developing a set of recommendations that sounded similar to the ideas being developed for RCA policy. That is not surprising, of course, since water conservation is a central thrust in both efforts. We have since combined our implementation efforts to create a more efficient policy process, and to at least improve the chances that outcomes are consistent with each other. There is a similar kind of relationship between RCA and the water quality program under RCWP. In all of these instances we should work to combine, rather than artificially split, policy development efforts.

We also continually face the problem of credibility. Are the decisions concerning our national program priorities the right ones? Are the recommendations we are providing to landowners valid and effective enough to get the job done? There are critical decisions that have to be made. We have to be conscious of the potential for a credibility gap between ourselves and the public or individuals to whom we are responsible, i.e., interest groups, the decision makers on Capitol Hill, the policy makers in the Executive Branch and within our own agencies, and the individual on whose land the work will have to be done if we are to solve the problems that face us.

I see it as our obligation and opportunity to help the farmer perceive his resource problems, the role he can perform and the commitment needed to solve that problem.

Conclusion No. 2 - We must encourage support for model development and adaptation, with a focus on usefulness of models for policy implementation. That support should come in budget decisions of various kinds and allocation of time and effort within the agencies. The key here is to demonstrate the "so what" dimensions of these models. Without that attention, modeling will appear to be a frivolous mathematical exercise with little payoff for the taxpayers who foot the bill. We must all realize that there is not unanimous support for models, modeling, or modelers, and we must keep a certain amount of humility in this process. The increasing premium on priority setting and evaluation in natural resource programs creates a fertile environment for greater attention to the opportunities to use models. We know that Congress is also developing better analytical capability. We must be able to find timely answers to performance questions. This workshop has demonstrated strongly that models and better data systems and resource monitoring contribute significantly to information needs at all levels.

Conclusion No. 3 - We must always bear in mind that analyses and models are not decisions. They are simply ways of combining information to facilitate decisions. We should not be so naive as to assume that the output of models leads directly to decisions. The judgement of policy makers is still the crucial variable, but models and monitoring can influence judgement by indicating the costs and impacts of decisions.

Our efforts to use models of various kinds, scales and degrees of complexity will help us to better visualize the future and the results of our efforts. We face difficult questions involving the allocation of very scarce resources. They must be answered in a timely manner, with limited funding and personnel available to us. The lines of communication that were opened by this conference and conferences like it will help make better decisions and help us to communicate with those who must pay the bill.

Conclusion No. 4 - There was an expressed need during this workshop for improved areas of technology transfer and the usefulness of center of excellence. EPA's plans for the Athens Laboratory as a modeling center to incorporate all types of water quality models may serve this purpose and help modelers in getting their act together.

We need information on the level of water quality needed in the various streams and water courses. To properly integrate and use this information, we need to include State water quality planners and regulatory people.

We need to better coordinate our modeling research efforts. We will accomplish some of this coordination through the EPA Iowa field evaluation that is conducted in conjunction with USDA. We need a whole series of models. There may be some repetition, but there are many needs that must be addressed. There is a real need for water quality monitoring and stream sampling, because Congress and others will ask for some evidence that water quality is improving and the programs are performing well. We must be able to say that implementation of BMP's has a decided impact on the water quality in the stream. Water quality monitoring programs must have the expertise and experience of people in the field. We may find we don't need as extensive a baseline data effort as many have contended except for the validation of models. In such cases the need for validating models and evaluating BMP's can be an extensive effort amounting to about three-fourths of the budget with only one-fourth going for the actual modeling.

Suggestions For the Future

1. The contact points between modelers, users, and various policy types should be increased. That contact can be enhanced internally within the agencies, and externally with universities and industry. I would encourage personnel policies within the agencies that permit short-term exchange of people playing various roles in policy implementation to achieve the kind of mixing of perspectives that can lead to real understanding. The outsider from the university or industry can contribute a specific skill, but perhaps more importantly, can offer a fresh perspective unencumbered by the kinds of internal struggles that may go on within an agency. The outsider with "selective ignorance" can be a real asset. Information exchange can be accomplished at workshops like this and with publications. But there is no substitute for more prolonged interaction among these individuals.

There is a certain chemistry involved in getting people together and an understanding that simply does not occur in shorter doses or through written materials. In the RCA process, for example, we have seen the kind of positive interaction among users and modelers that has produced what is an effective policy process.

2. We would like to see some intensive seminaring with behavioral scientists in a setting just like the one we've had here for the past two days. Behavioral scientists can add additional insights to policy implementation that help us predict the real outcomes of different programs. We must reach a better understanding of how people act and how they respond to physical and biological data on water quality or other resource problems. We know that these data, filtered through the mental processes of individuals, influence and affect human values. We also know that people with similar values often come together in political groups and seek to inject those values into decisions. Behavioral scientists have predictive theories and formal models about human interaction that can be most instructive in policy development and implementation.

In this same light, we need to focus attention on organizational behavior--that is, how agencies respond to external stimuli such as a new resource law, or a major court decision, or an Executive Order. How does the agency adjust? Or does it adjust? Does it simply envelop this outside challenge, absorbing it into the ongoing processes, and not change? Does the agency radically restructure with all sorts of internal stress? There are theories and empirical studies that would be instructive and useful in trying to conduct resource policy. We should hold a 2-1/2 day seminar here at Airlie House focusing on the contributions of the behavioral sciences.

Where we go from here is not clearly charted. It is largely a function of how important the public, we in the Executive Branch, the Congress, the landowner, you, and I perceive the problem to be. One thing is for sure, we won't solve the problem until we perceive that the problem is worth solving.

ASSESSING WATER QUALITY CHANGES:

MONITORING, MODELING OR A COMBINATION?

Marshall E. Jennings, U.S. Geological Survey

In recent years considerable progress has been made in monitoring and modeling techniques related to water quality planning problems. Thus today the tools of monitoring and modeling are potentially very useful to support planning, implementation, and evaluation activities of rural water quality project planning. Definitions of water quality monitoring and water quality modeling, which recognizes today's scope of water quality planning, are as follows:

Water Quality Monitoring

> A selected strategy of repeated field sampling and/or laboratory determination, data handling, and analysis designed to produce information, according to particular time and space scales for trend determination, planning, standards enforcement, or input to water quality models.

Water Quality Modeling

> Application for planning or assessment purposes of a statistical or deterministic calculation procedure, which has been successfully calibrated and verified using field data and which adequately describes the processes of watershed runoff, water quality transport, and chemical and physical interaction.

As suggested in the question of the title, these activities may not necessarily be mutually exclusive, e.g., information from a monitoring system may be utilized in a water quality model.

This paper first discusses general aspects of water quality monitoring and modeling. Then, because instrumentation and data acquisition are fundamentally important in water quality planning, a brief section is devoted to representative water quality monitoring instrumentation and associated data handling activities in use by the U.S. Geological Survey. Finally, the concepts of monitoring and modeling are illustrated with reference to a recently completed water quality assessment of the L'Anguille River, Arkansas.

Water Quality Monitoring

Since the passage of the Federal Water Quality Act of 1965, the need to monitor water quality for regulatory purposes in relation to stream standards has been written into most laws that have established water quality management programs. Although the regulatory monitoring purpose is dominant, other monitoring purposes, including general water quality assessment, detection of short-term extremes, identifying the nature of long-term trends, and compilation of data for modeling are also important.

Whatever the purpose of monitoring, given fixed funding, a regulatory or planning agency has to strike a balance between a monitoring network based on a fixed-station, perhaps high-frequency sampling concept and the concept of intensive, synoptic surveys. Above all, the objectives of the monitoring program should be clearly defined prior to the actual monitoring network design.

The fixed-station, high-frequency monitoring concept is aimed at determining phenomena in time whereas the synoptic survey is designed for determining spacial aspects, perhaps in relation to a critical water-quality condition. The synoptic survey concept has a fixed termination date, usually after a few days of sampling, while the fixed-station concept utilized long-term and continuous operation at the given sampling frequency. Sampling frequency may range from hours to months. Depending on the water quality phenomena being monitored, these concepts (which differ in time and space scales as per the above definition of monitoring) may be complementary, particularly if the same variables and sampling procedures are employed within a given network.

Recent emphasis has been on the utility of the more cost-effective synoptic survey concept, particularly in cases of nonpoint sources of pollution. However, both concepts have merit depending on the required application. For example, the U.S. Geological Survey utilizes the fixed-station concept for its National Stream-Quality Accounting Network (NASQAN) of approximately 500 stations but also uses the repeated synoptic survey concept for its program of river quality assessments. A combination of both concepts is suggested as a useful monitoring strategy for rural water quality programs.

A monitoring system should be viewed as a sequence of operational activities including network design, sample collection, laboratory analysis, and information utilization as suggested by Ward (1979), and Haseman, Lieberman and Whinston (1975), (See figure 1). While each of these activities is important for a successful monitoring system, good network design is most important. Network design for establishing station location for two or more monitoring stations, although fundamentally important, is apparently an intractable analytical problem. However, informal criteria for establishing station location are helpful (Lettenmaier 1978):

1. Make use of existing stations or stations at which earlier data from discontinued stations is available.

2. Locate stations so as to monitor a substantial proportion of the total runoff from a river basin. In general, this consideration favors location of stations as far downstream as is possible, consistent with other factors.

3. Stations should be located so that analysis of data collected at the given station taken together with data collected at adjacent stations can isolate effects of land-use changes.

4. Sample stations should be located such that a representative sample of the cross-sectional stream quality is obtained using an appropriate sampling technique such as single vertical, depth integration, equal width increments or equal discharge increments.

5. Care should be taken to locate stations so that local effects do not interfere; for instance, stations should not be located in areas where major highway construction, stream channelization, etc., are planned or appear likely unless it is desired to assess the impact of these projects on stream quality.

6. At each established station, it is desirable to establish a correction survey to compenstate for diurnal effects. This may be

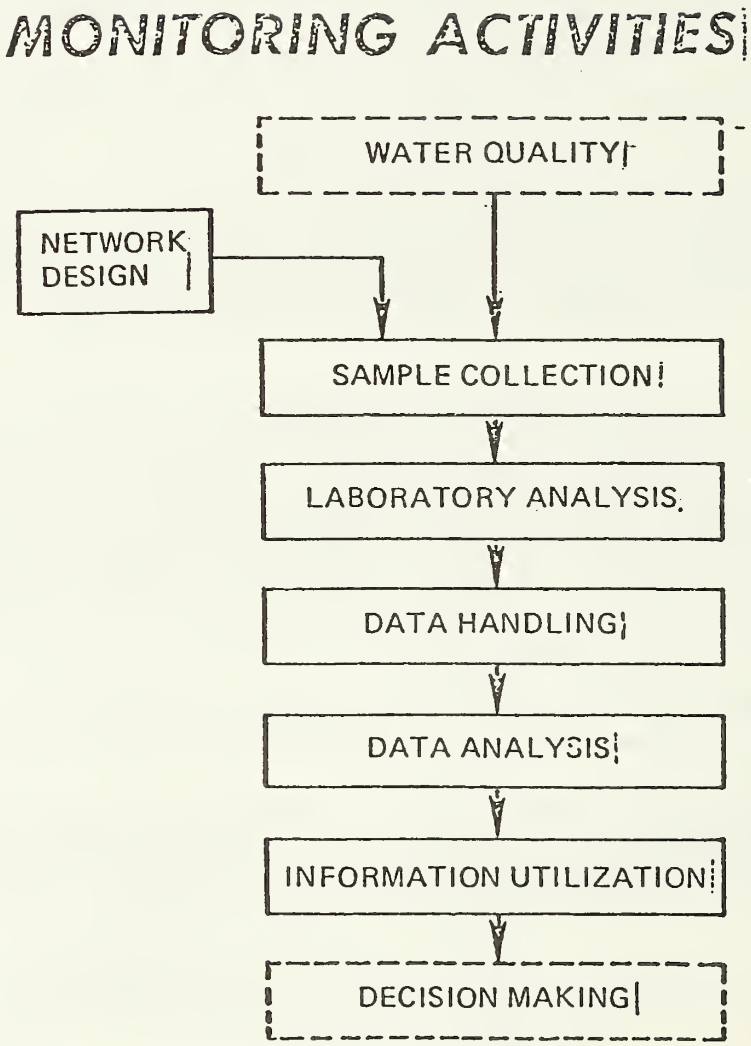


Figure 1.--Activities sequence for an ideal monitoring system, after Ward (1979).

accomplished by use of an automatic monitor to collect high frequency data over several days, possibly seasonally. Samples should then be corrected to a common sampling time; for instance, 12:00 noon. For some parameters diurnal variations may be negligible; however, for biologically influenced variables (e.g. dissolved oxygen, etc.) slight variations in the time at which samples are collected can induce extra variability or even spurious trends in the data.

7. When compatible with considerations 1-6, stations should be located in such a manner as to minimize sample transport time and sample crew travel requirements.

As pointed out by Ward (1979) the activities shown in figure 1 should be part of a well-balanced, smoothly operating monitoring system. The goal is to collect data which can be efficiently converted to information to assist decision making.

Water Quality Modeling

Also beginning about 1965, a tremendous upsurge of research has produced a well advanced state-of-the-art in water quality modeling both of the statistical and deterministic types. See Environmental Protection Agency (1979) for an excellent overview of deterministic models. Statistical modeling has generally focused on available data from the relatively few fixed-stations with high-frequency sampling for which time-series analysis is appropriate. Deterministic models, both of the watershed runoff quality and channel transport types, generally make use of data from synoptic surveys.

Most research has been performed in the area of deteministic models. Representative of watershed deterministic models are the NPS and ARM models, Donigian and Crawford (1976), Donigian and Davis (1978), which probably represent state-of-art. However, these tools are still quite crude representations of the complex processes of infiltration and runoff, erosion, sediment and pollutant transport typical of watershed response. Particularly difficult to analyze are watersheds larger than a few square miles that include significant spacial variations in watershed and precipitation characteristics.

Deterministic models of channel transport processes are somewhat more refined and descriptive of actual phenomena than deterministic watershed models. Both steady-state (constant or spacially variable flow and constant parameters) and unsteady-state models (time variable flow and other parameters) are available. For example, USGS models of each type are respectively Bauer, Jennings, and Miller (1979) and Bauer and Bennett (1976). Fully adequate channel transport models for generalized water quality planning applications are yet to be convincingly verified. However, channel transport models such as QUAL II, Evenson and others (1974), which have been widely applied, show considerable promise as generally useful tools. An adequate data base remains a constraint for continued progress in water quality modeling. Adequate data is essential for the calibration and verification phases of model application. Traditionally calibration data sets have been used to determine model parameters while independent verification data sets have been used to confirm model performance. Through extensive data set testing using varied field situations, a particular model may, through refinement, achieve wide acceptance as a state-of-art

technique. While a substantial network of continuous streamflow gaging stations exists in the U.S. (>10,000 sites), comparatively, the number of water quality gaging stations is very sparse. It should be obvious, however, that the cost of operating a continuous, daily water quality station for a suite of constituents far exceeds daily streamflow gaging. In addition, the number of water quality constituents of interest is constantly being enlarged.

Because rural water quality models require substantial data to achieve credibility via calibration and verification, a well-designed combination monitoring/modeling program is recommended as a best approach.

Water Quality Monitoring Instrumentation

The advent of automatic monitors has considerably strengthened water quality monitoring capabilities. For example, in 1973 Ward and Vanderholm (1973) reported that grab or manual methods sampling was still the backbone of most water quality monitoring systems. Today there is a substantial use of automatic monitors and mini-monitors such as those used by the U.S. Geological Survey.

The USGS Water Quality Monitor is a system designed to measure and record up to 10 water quality parameters. The system comprises the following items: wall mounted cabinet, sensors, sample chamber, timer and recorder. The cabinet contains the programmer, signal conditioners, buffers, power supplies and standby batteries and requires 115V AC. The sample chamber can hold up to six sensor assemblies and requires a continuous flow through wate samples of at least 5 gal/min. A digital input and output recorder and a crystal timer are utilized in the system which punches on a paper tape for ADP processing. The standard monitor has the capability to measure and record four parameters--conductivitiy, temperature, dissolved oxygen and pH.

The USGS Mini Monitor is a system designed to record up to four water quality parameters (eight parameters in an expanded version). The system contains a battery-operable electronics package, a digital input and output 16-channel paper-tape recorder, along with probes and extension cables with underwater connectors.

In operation the unit turns itself on every recording interval, scans, and records the parameters on paper tape and then turns itself off until the next recording time. The recording interval is controlled by an internal crystal clock and is programmable from 1 to 79 minutes. Unlike the USGS flow-through monitor, the probes can be placed directly in the river thus eliminating the pump and sample chamber. However, the system will also function with the probes in a sample chamber if desired. Mini-monitors are currently available to measure temperature and conductivity. Dissolved oxygen and pH systems will soon be added. In addition, research is in progress on an optical system for turbidity and/or associated water-column properties. A watertight round container 10" high by 10 1/2" diameter houses the minimonitor electronics unit. Approximately 50 units are in the field, two being operated with satelite telemetry. Within the next 3 years, approximately 450 mini-monitors are projected to be operating in the field.

Because the USDA integrates both types of USGS water quality monitors into the WATSTORE data processing system, essentially all the activities shown in figure 1 are incorporated into the monitoring system. If required, manual-sampling and automatic sequential water quality sampling can be operated in parallel with a continuous monitor.

L'Anguille River Basin Assessment

The recently completed L'Anguille River Basin assessment, Bryant, Morris and Terry (1979), offers an illustration of monitoring and modeling applications. For several years dissolved oxygen in the L'Anguille River in northeast Arkansas (figure 2) has been reduced to concentrations of less than 5 mg/L during the summer and fall. In addition, concentrations of pesticides have been reported consistently at one of two long-term monitoring sites on the river and trace metals have been reported at both monitoring sites near Colt (station 20) and Marianna (station 34) (figure 3). The oxygen depletion has not resulted totally from biochemical-oxygen demand and nitrogen loadings from municipal-waste facilities (figure 4) whose effluents enter the river as point sources.

To document the causes of oxygen depletion and the occurrence of pesticides and trace metals in the basin as well as to assess the general water quality, the U.S. Geological Survey conducted intensive studies of the basin during the summer and fall of 1978. Figure 5 shows the daily hydrograph at station 6 for the "average" runoff year, 1976 -- the river has a 7-day, 10-year low flow of less than 0.1 ft 3/s at that location. Because the L'Anguille River is predominantly an agricultural area, return irrigation flows comprise much of the low flow of the river. These flows carry residuals of nutrients and pesticides applied to soybean, cotton and rice crops in the basin.

Data from two long-term water quality monitoring stations were studied in order to plan to synoptic surveys of August 21-25, and October 21-November 2, 1978 which involved diel-oxygen, temperature, benthic organism, pesticide and trace metals in fish, and streambed-oxygen-demand sampling. In addition, samples of common constituents collected at the two monthly monitoring sites since the early 1970's were collected at all sites. After a 3-inch rain on November 17, 1978, sediment samples and additional water quality samples were collected at sites near the upper end of the basin. Basin-wide sediment, mostly from sheet and till erosion, is estimated at 788,600 tons/year of which an estimated 410,400 tons is delivered to the mouth of the L'Anguille River.

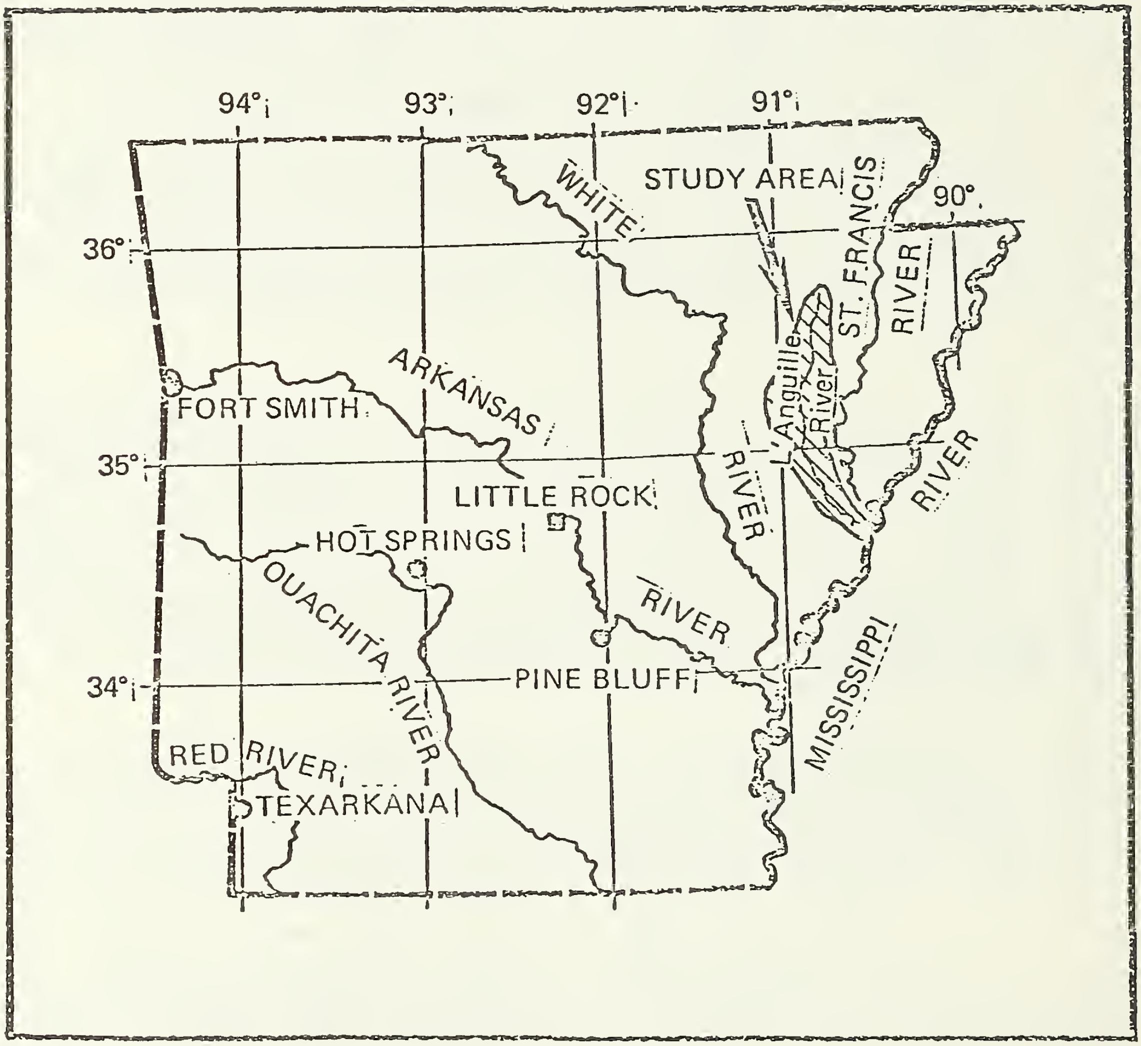


Figure 2.--L'Anguille River Basin.

Figure 3.--

L'ANGUILLE RIVER BASIN SHOWING SAMPLING SITES

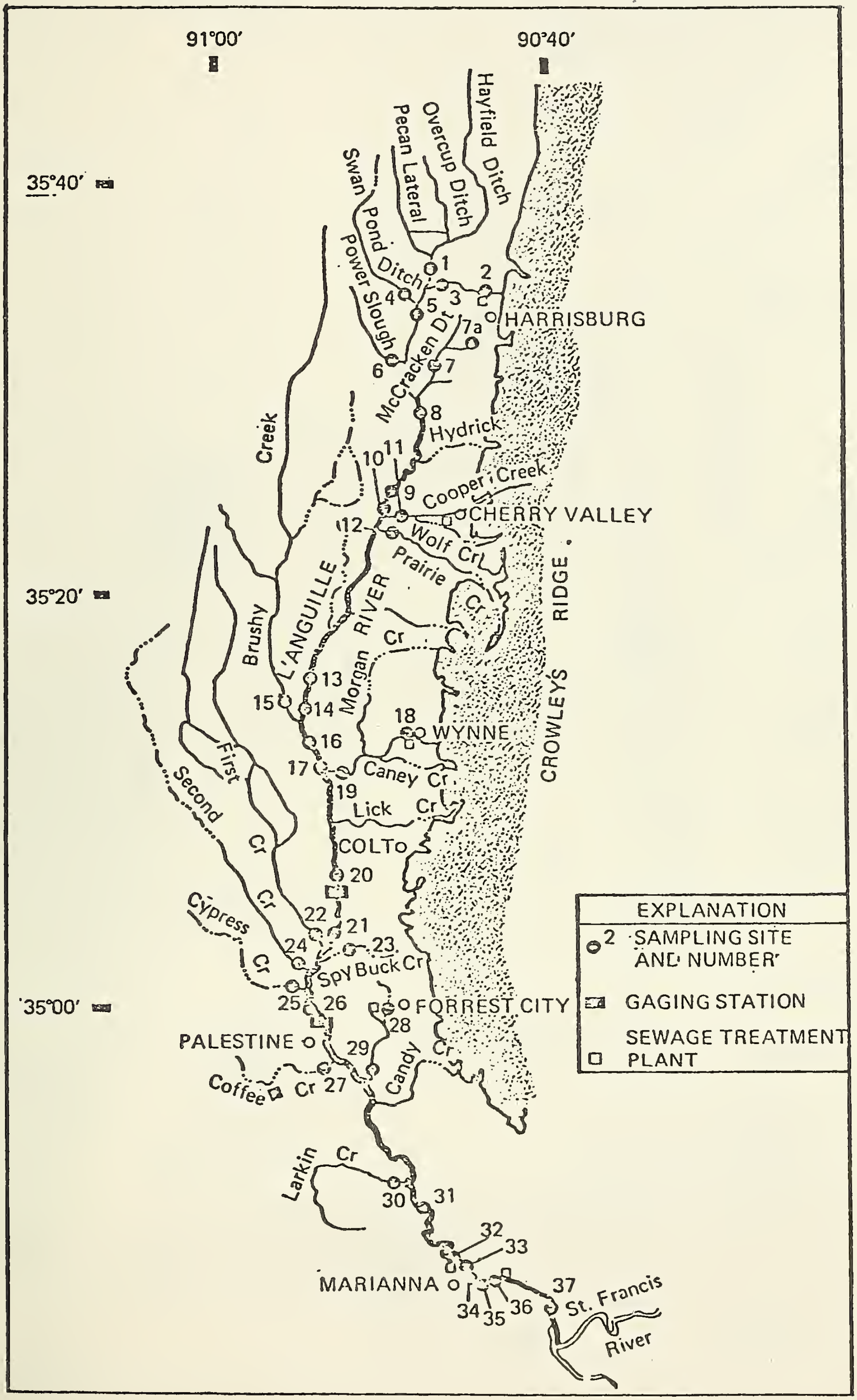


Figure 4.--L'Anguille River showing point sources.

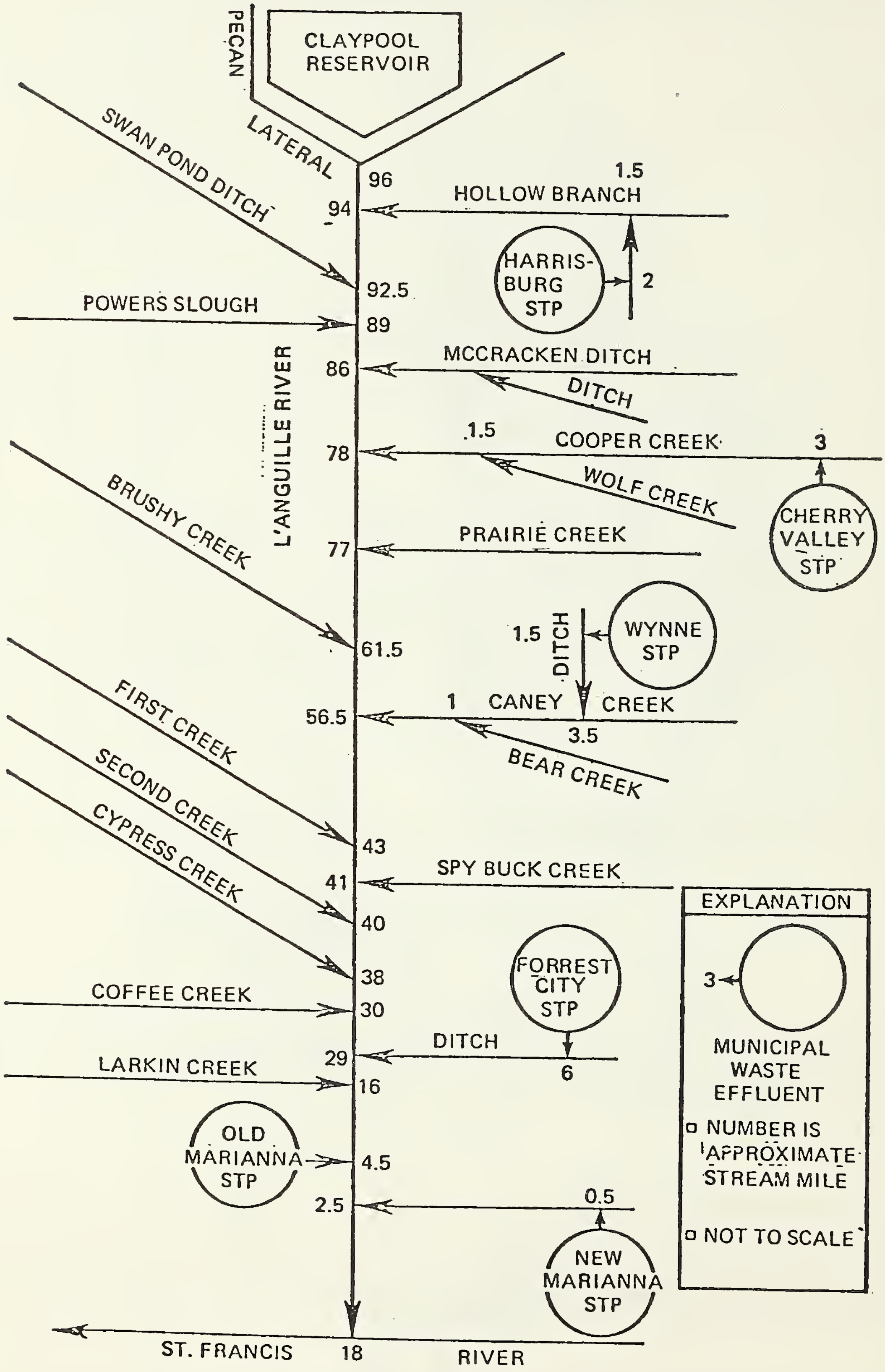
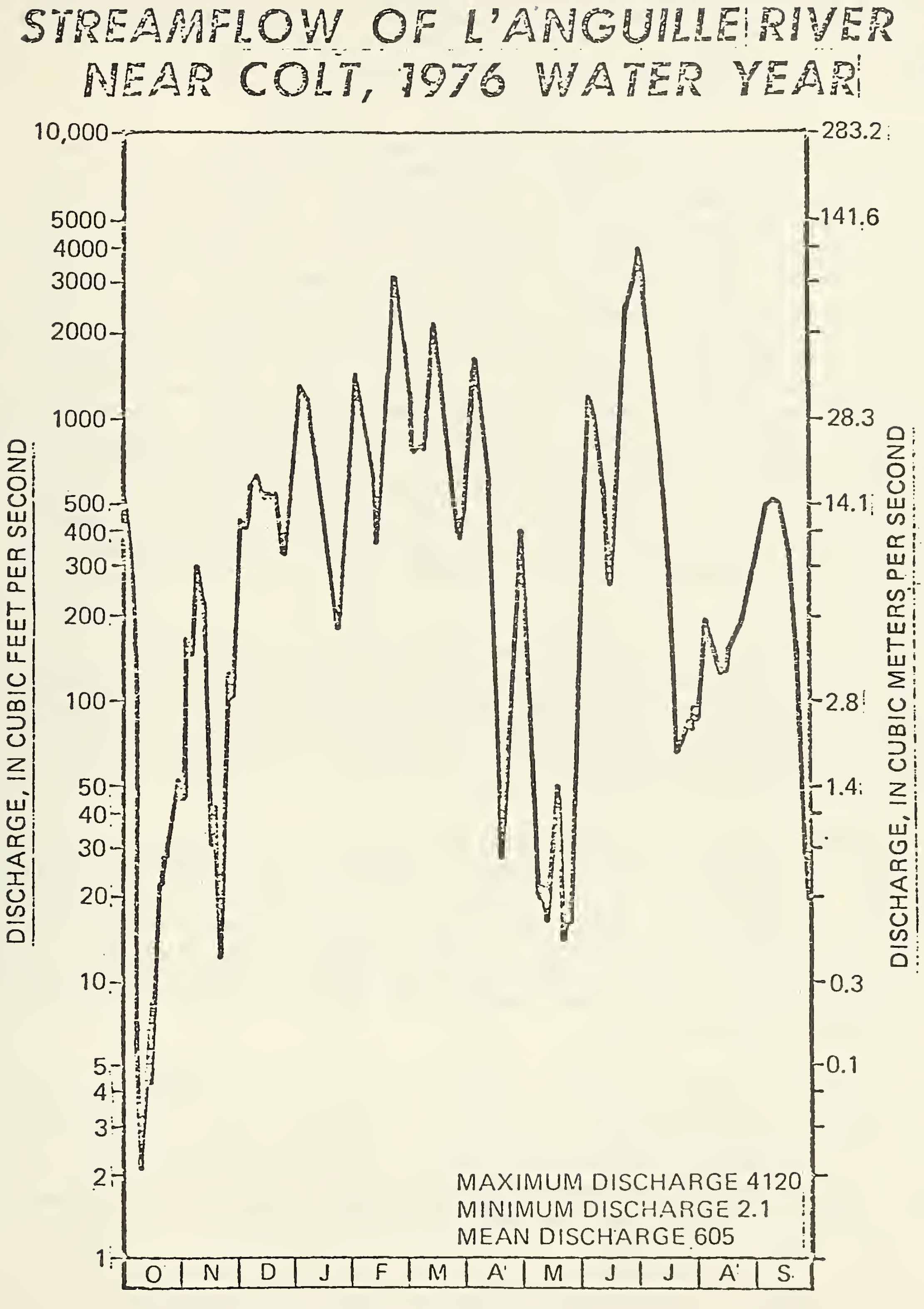


Figure 5 .--


STREAMFLOW OF L'ANGUILLE RIVER
NEAR COLT, 1976 WATER YEAR
DISCHARGE, IN CUBIC FEET PER SECOND
DISCHARGE, IN CUBIC METERS PER SECOND
10,000
5000
4000
3000
2000
1000
500
400
300
200
100
50
40
30
20
10
5
4
3
2
1
283.2
141.6
28.3
14.1
2.8
1.4
0.3
0.1
MAXIMUM DISCHARGE 4120
MINIMUM DISCHARGE 2.1
MEAN DISCHARGE 605
O
N
D
J
F
M
A
M
J
J
A
S

Because of low stream velocities, large sand deposits are found along the streambed. Figures 6 and 7 show a statistical summary of trace metals and common constituents from historical monitor records at Colt. Figures 8 to 11 show the average and ranges from the long-term monitor records for selected physical and chemical parameters. The monitoring records were of significant value in designing the synoptic surveys which in turn were used in the water quality modeling application.

It was quickly realized that the oxygen budget was being significantly altered by oxygen demand from the streambed. Accordingly, a laboratory respirometer designed by USGS staff in Arkansas (figure 12) was used to obtain special measurements of streambed oxygen demand shown in figure 13. These and other measurements including point waste sources, were used in a one-dimensional, steady-state, water quality model, (Bauer, Jennings, and Miller, 1979). Data collected in August 1978 (figure 14) were used to calibrate the model and data collected during the November synoptic survey were used to verify the model. Constituents included in the L'Anguille model as predictable variables are dissolved oxygen, carbonaceous biochemical oxygen demand, nitrogen forms (organic, ammonia, nitrite, nitrate), total and fecal-coliform bacteria, orthophosphate-phosphorous, and total suspended solids. Stresses on the system included utilization of oxygen by carbonaceous and nitrogeneous substances and benthic deposits, the uptake of phosphate by streambed materials, the die-off of total-and-fecal-coliform bacteria, and reaeration of the stream. Except for the upper part of the stream, photosynthesis and respiration were not considered a significant source and sink of dissolved oxygen.

During calibration the benthic (or streambed) demands upon oxygen in the stream were much more significant than either the carbonaceous or nitrogeneous demands amounting to more than 90 percent of the oxygen deficit in each subreach. Figure 15 shows the calibrated oxygen profile and the model simulated profile which is projected to result if an estimated 40 percent reduction in benthic oxygen demand could be achieved.

The failure to meet State standards for oxygen in the L'Anguille River is related to a non-point source, namely, sheet and till erosion of sediment sources. Low stream velocities allow much of the sediment-laden organic material, consisting of silt, clay, organic detritus and some sand and gravel, to be deposited on the streambed. A high streambed oxygen demand is caused by respiration of bacteria, fungi, and invertebrates living on or in the streambed. Low reaeration and high summer temperatures are also factors in the occurrence of the high oxygen demand.

A more detailed modeling study, incorporating a linked watershed-water quality model capable of determining erosion rates and transport mechanisms in relation to tillage practices would be required to determine the exact relation between origins of nonpoint sediment and associated constituent sources and stream oxygen deficits. Such an effort is a logical extension of the present monitoring and modeling system used for the L'Anguille River Basin assessment and is presently being considered.

The availability of monitoring records in the L'Anguille basin was of significant benefit in planning the synoptic surveys required for modeling. Using the monitored information, historic trends of important variables were quickly identified allowing a proper focus for the specific objectives of the modeling study.

Figure 6.--

STATISTICAL SUMMARY OF TRACE METALS, L'ANGUILLE RIVER NEAR COLT

Trace metals	Number of samples analyzed	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
Arsenic, total (µg/L as As)-----------	6	3.7	1.4	2.00	6.00	0.56
Cadmium, dissolved (µg/L as Cd)-----------	16	.69	.8	.0	2.0	.20
Cadmium, total recoverable (µg/L as Cd)------	6	3.3	5.2	.0	10	2.1
Chromium, dissolved (µg/L as Cr)-----------	11	6.2	7.8	.0	20	2.3
Chromium, Total recoverable (µg/L as Cr)------	6	5.0	8.4	.0	20	3.4
Cobalt, dissolved (µg/L as Co)-----------	16	1.1	1.7	.0	5.0	.4
Cobalt, Total recoverable (µg/L as Co)-----------	4	38	24	2.0	50	12.0
Copper, dissolved (µg/L as Cu)-----------	16	8.6	6.6	2.0	30	1.7
Copper, total recoverable (µg/L as Cu)-----------	6	8.8	5.6	.0	17	2.3
Iron, dissolved (µg/L as Fe)-----------	16	140	166	.0	610	41.5
Iron, total recoverable (µg/L as Fe)-----------	6	1,767	1,116	1,100	4,000	456.9
Lead, dissolved (µg/L as Pb)-----------	16	2.4	3.0	.0	9.0	.8
Lead, total recoverable (µg/L as Pb)-----------	6	51	53	.0	100	21.8
Manganese, dissolved (µg/L as Mn)-----------	16	276	304	30	1,100	76.0
Manganese, total recoverable (µg/L as Mn)----	6	805	345	440	1,200	141.0
Mercury, dissolved (µg/L as Hg)-----------	12	.3	.3	.0	.8	.08
Mercury, total recoverable (µg/L as Hg)------	8	1.3	3.5	.0	10	1.2
Selenium, dissolved (µg/L as Se)-----------	7	1.6	2.3	.0	6.0	.9
Selenium, total (µg/L as Se)-----------	6	3.0	4.0	.0	9.0	1.6
Zinc, dissolved (µg/L as Zn)-----------	16	23	12	.0	40	2.9
Zinc, total recoverable (µg/L as Zn)-----------	6	42	25	10	80	10.1

Figure 7.--

STATISTICAL SUMMARY OF COMMON CONSTITUENTS, L'ANGUILLE RIVER NEAR COLT

Constituent	Number of samples analyzed	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
Specific conductance (micromhos)-------------	109	232	150	62	547	14.4
pH (units)----------------	109	7.3	.4	5.9	8.4	.04
Oxygen demand, chemical (low level (mg/L)-------	63	31	13	.0	75	1.6
Hardness (mg/L as $CaCO_3$)---	18	105	74	23	250	17.3
Hardness, noncarbonate (mg/L as $CaCO_3$)---------	18	3.0	5.2	.0	18	1.2
Calcium, dissolved (mg/L as Ca)------------	18	26	18	6.0	59	4.2
Magnesium, dissolved (mg/L as Mg)------------	18	9.6	7.4	2.0	24	1.6
Sodium, dissolved (mg/L as Na)------------	18	12	8.8	3.0	34	2.1
Sodium adsorption ratio---	18	.5	.2	.3	1.0	.04
Potassium, dissolved (mg/L as K)-------------	18	4.8	2.1	2.5	9.6	.50
Bicarbonate (mg/L as HCO_3)-----------	50	108	84	20	302	12
Carbonate (mg/L as CO_3)----	50	.0	.0	.0	.0	.0
Alkalinity (mg/L as $CaCO_3$)---------	54	95	72.4	16	248	9.8
Sulfate, dissolved (mg/L as SO_4)-----------	19	13	7.2	4.4	29	1.6
Chloride, dissolved (mg/L as Cl)------------	19	14	11	3.0	47	2.5
Fluoride, dissolved (mg/L as F)-------------	19	.2	.1	.0	.3	.02
Silica, dissolved (mg/L as SiO_2)-----------	19	12	6.8	3.9	24	1.6
Solids, residue at 180°C, dissolved---------	17	155	94	46	332	22.7
Carbon, organic total (mg/L as C)-------------	16	12	4.4	7.3	24	1.1

Figure 8.--

RANGE AND AVERAGE TOTAL PHOSPHORUS CONCENTRATIONS, L'ANGUILLE RIVER NEAR COLT, OCTOBER 1970 THROUGH SEPTEMBER 1978

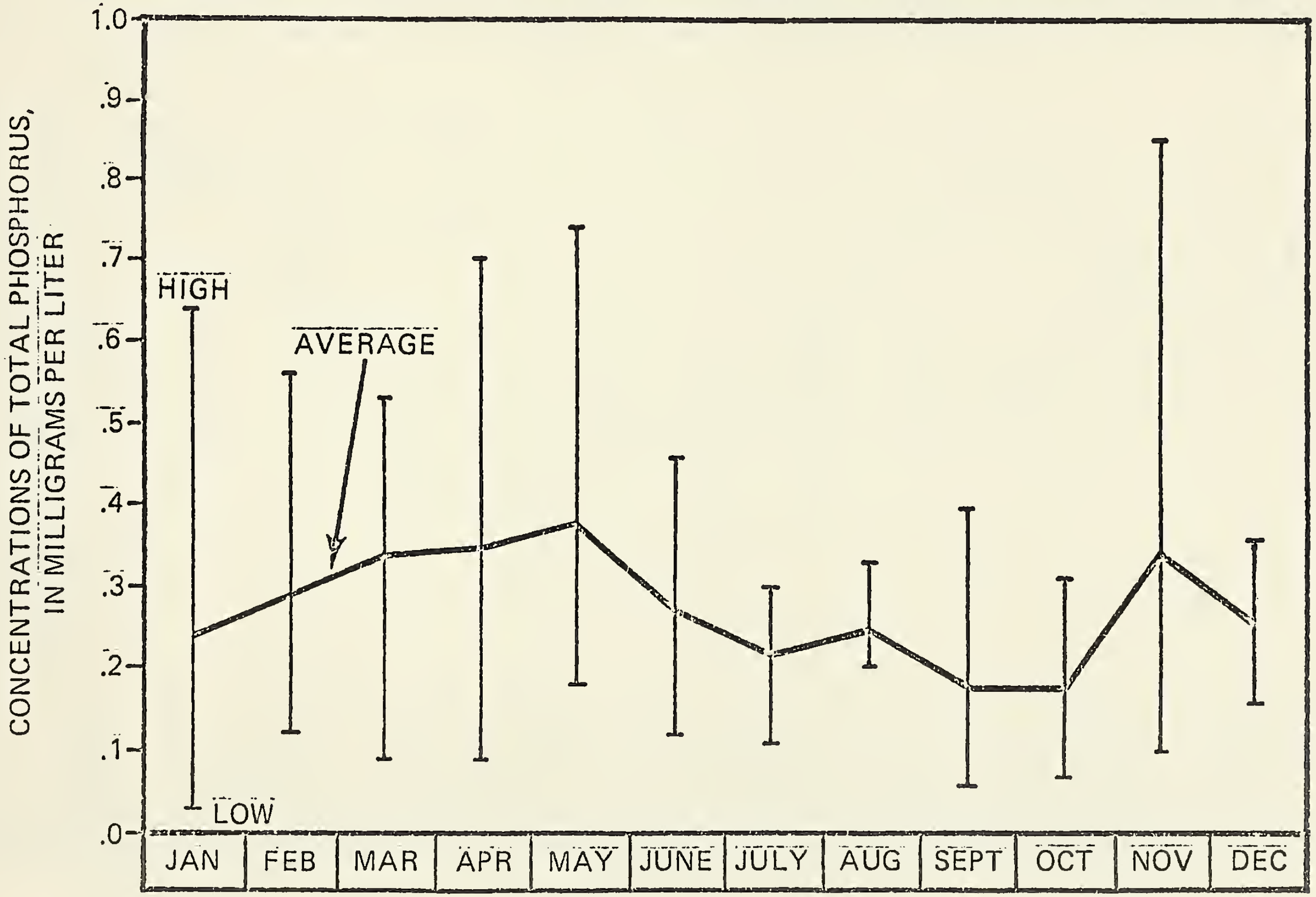


Figure 9.--

RANGE AND AVERAGE TOTAL NITROGEN CONCENTRATIONS, L'ANGUILLE RIVER NEAR COLT, OCTOBER 1970 THROUGH SEPTEMBER 1978

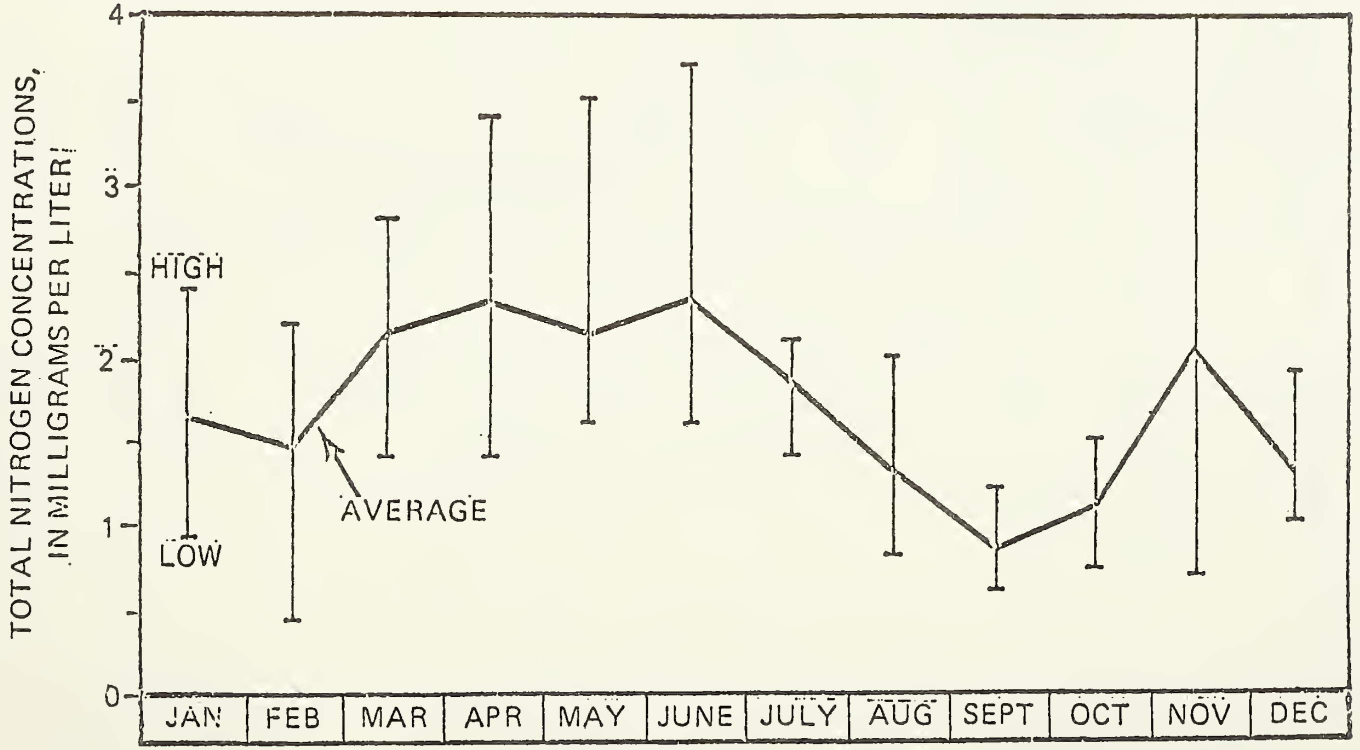


Figure 10.--

RANGE AND AVERAGE DISSOLVED-OXYGEN CONCENTRATIONS, L'ANGUILLE RIVER AT MARIANNA, OCTOBER 1974 THROUGH SEPTEMBER 1978

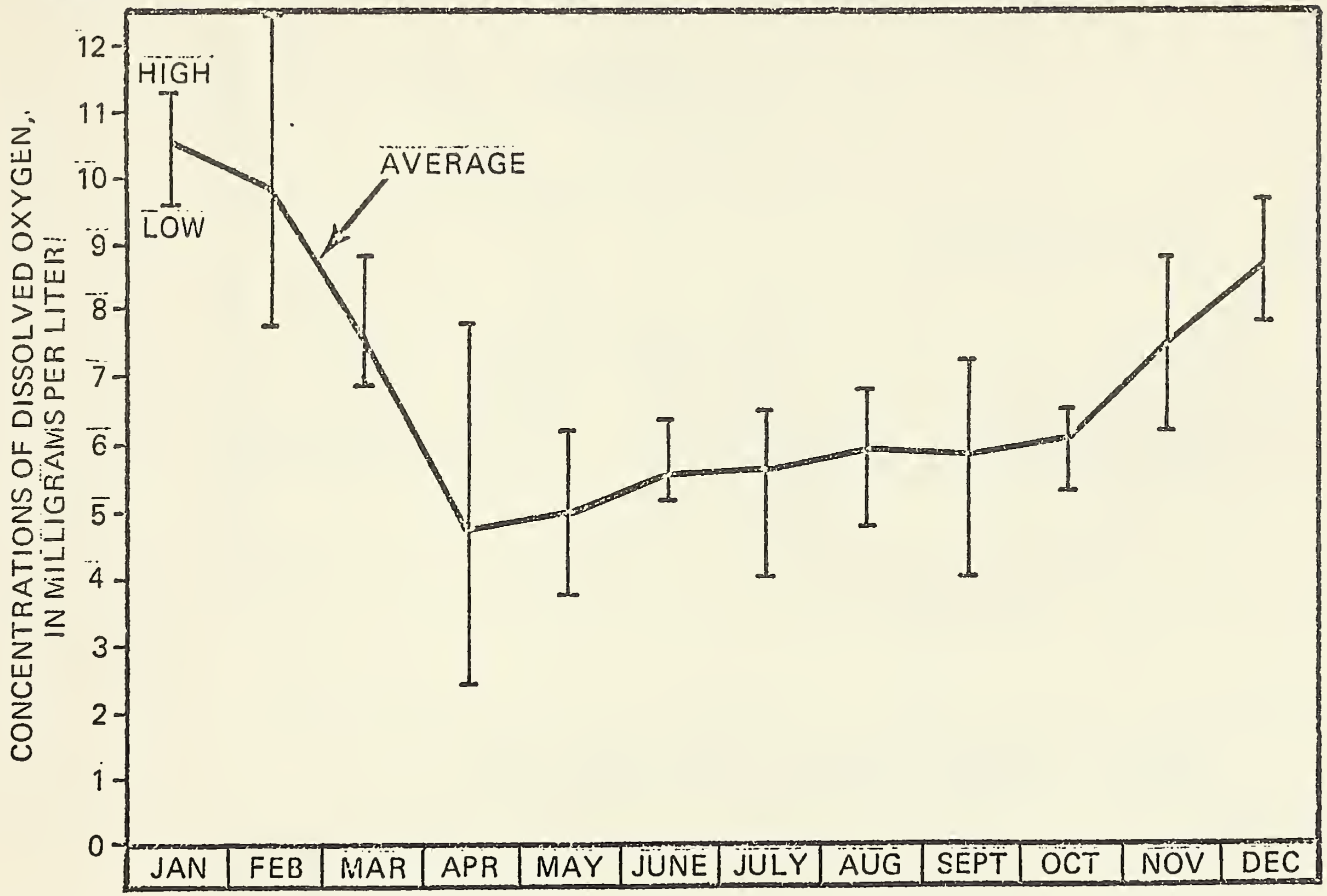


Figure 11.--

RANGE AND AVERAGE WATER TEMPERATURES, L'ANGUILLE RIVER NEAR COLT, OCTOBER 1970 THROUGH SEPTEMBER 1978

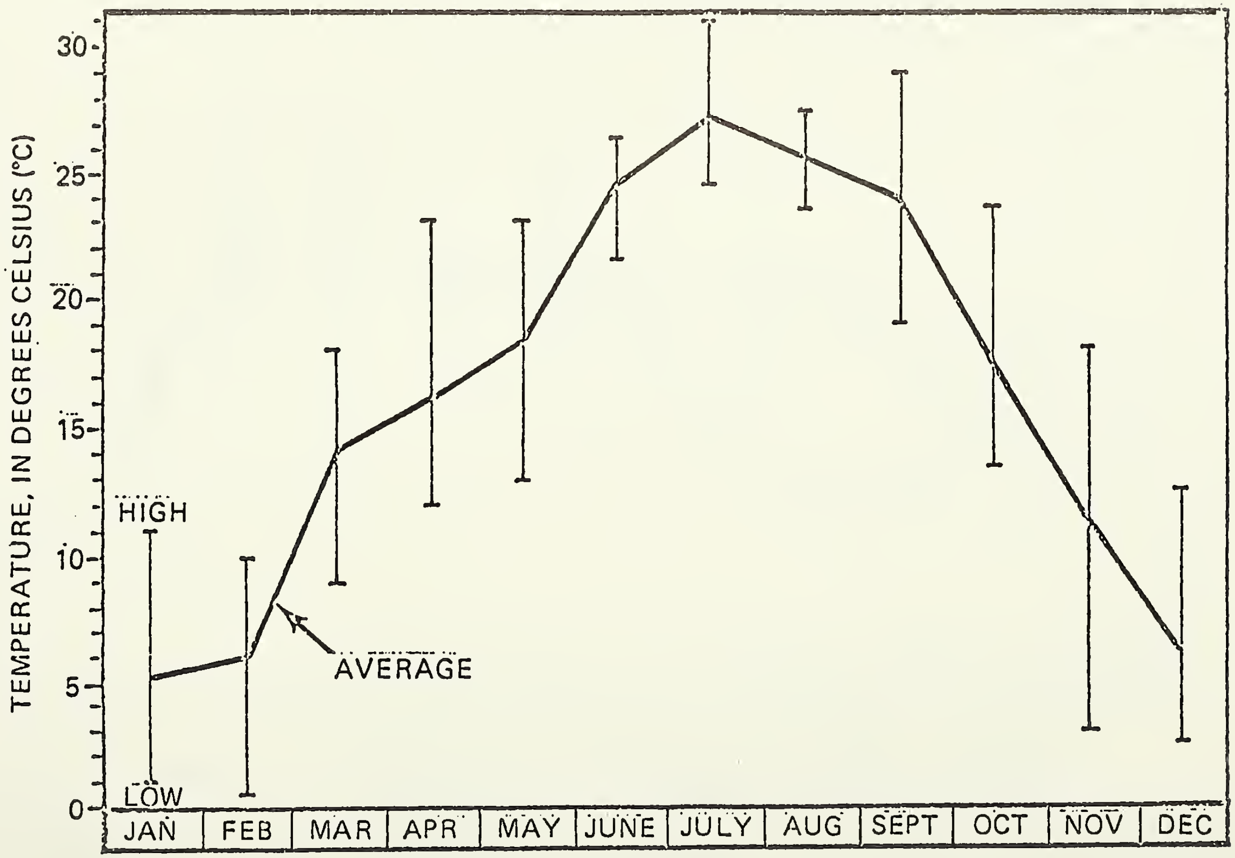


Figure 12.--

RESPIROMETER USED FOR MEASURING STREAMBED-OXYGEN DEMAND

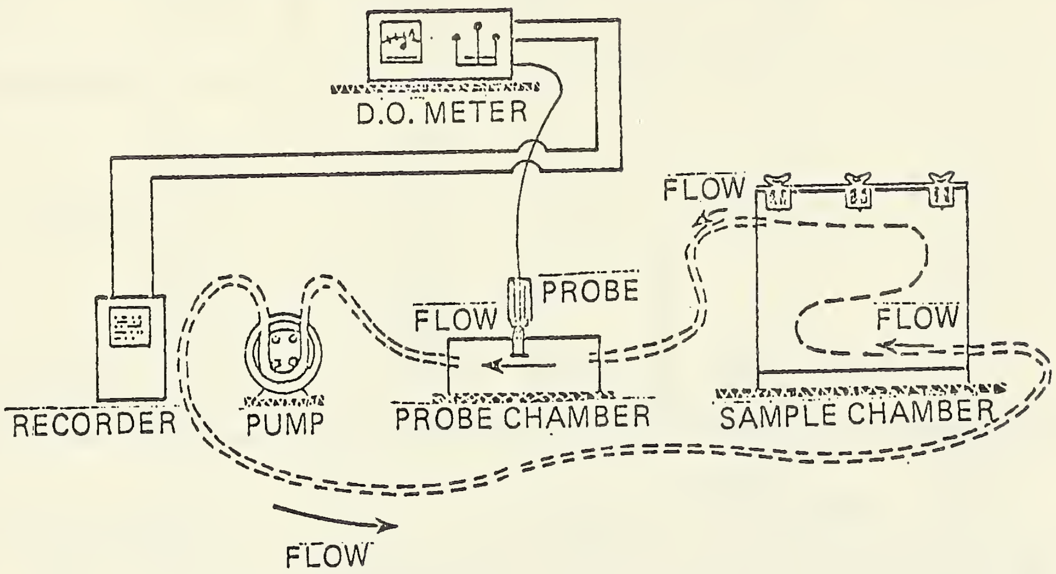


Figure 13.--

STREAMBED-OXYGEN DEMANDS OF THE L'ANGUILLE RIVER

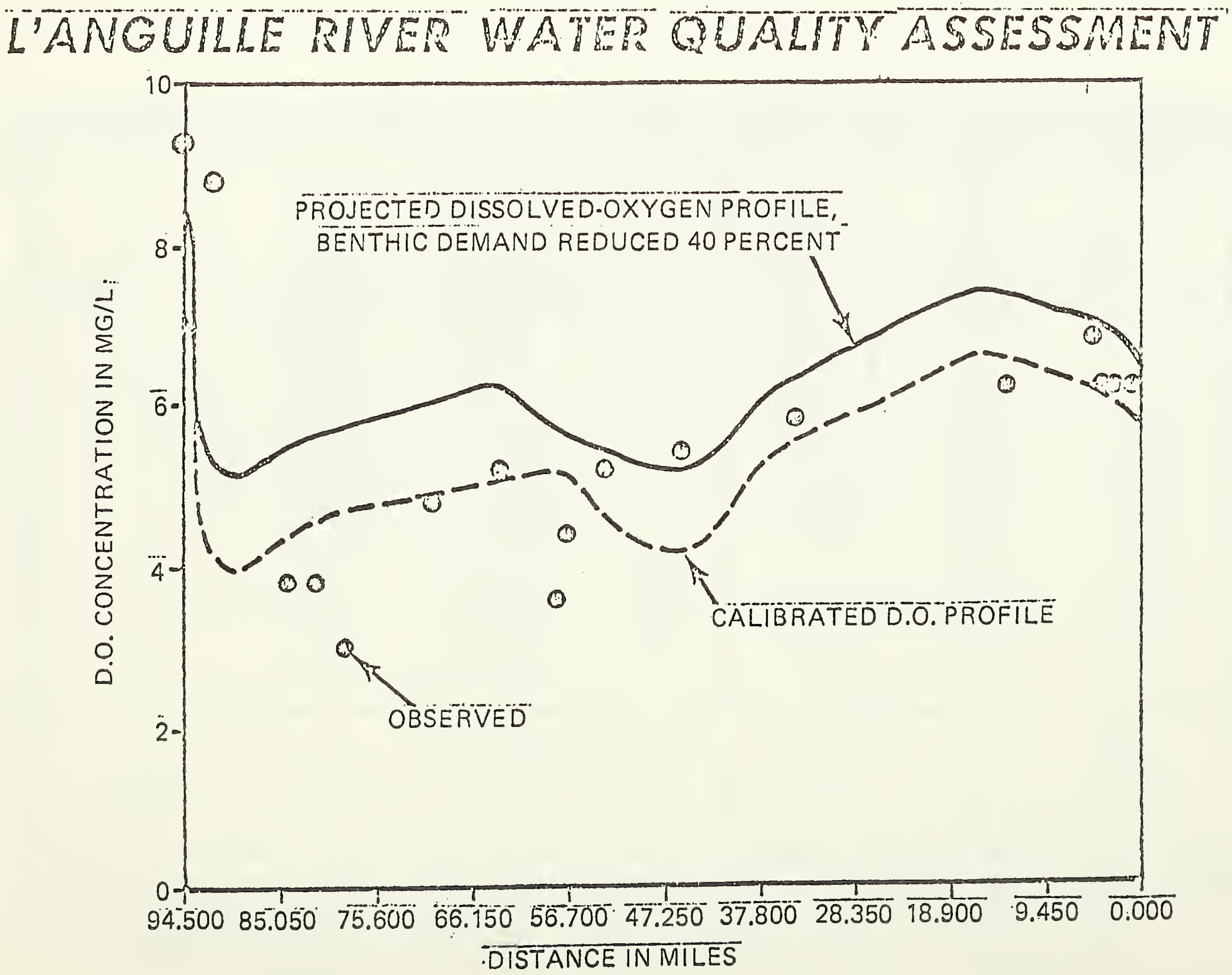
Station location	Station number	Date of collection	Run number	Respiration $gO_2/m^2/day$	Mean respiration rate	Standard deviation of the mean	95-percent confidence limit of the mean		Streambed description
							upper	lower	
Near Cherry Valley	10	12-27-78	1 2 3 4	3.48 4.13 4.28 2.54	3.61	0.79	4.87	2.35	Yellow clay with some sand and small roots.
Near Colt	20	11-28-78	1 2 3	4.67 5.61 3.86	4.71	0.88	6.20	3.22	Black silt with some sand and leaves.
At Marianna	34	10-18-78	1 2 3	4.65 3.16 5.26	4.36	1.08	6.17	2.55	Black silt.

Figure 14.--

AVERAGE DISSOLVED-OXYGEN DEFICITS CREATED IN EACH SUBREACH--CALIBRATION RUN

Subreach number	Beginning mile	Ending mile	CBOD deficit (mg/L)	Benthal deficit (mg/L)	Ammonia deficit (mg/L)	Nitrite deficit (mg/L)
1	94.50	94.00	0.010	0.530	0.013	0.001
2	94.00	92.50	.017	.463	.023	.004
3	92.50	89.00	.009	.253	.013	.002
4	89.00	86.00	.005	.171	.010	.002
5	86.00	78.00	.0	.137	.009	.002
6	78.00	77.00	.0	.082	.006	.001
7	77.00	61.50	.0	.109	.005	.001
8	61.50	56.50	.0	.094	.003	.001
9	56.55	43.00	.0	.090	.003	.001
10	43.00	41.00	.0	.037	.001	.0
11	41.00	40.00	.0	.054	.002	.0
12	40.00	38.00	.0	.041	.002	.0
13	38.00	30.00	.0	.038	.002	.0
14	30.00	29.00	.0	.033	.002	.0
15	29.00	16.00	.0	.027	.002	.0
16	16.00	4.50	.0	.035	.002	.0
17	4.50	2.50	.0	.030	.002	.0
18	2.50	0.00	.0	.040	.003	.001

Figure 15.--Computed and observed L'Anguille River Oxygen Profiles



Conclusions

Rural Clean Water Program activities of the Department of Agriculture arising out of the 1977 amendments of PL 92-500 section 208j should benefit from advances in water quality monitoring and modeling made in the last decade. A monitoring program based on a fixed-station network but with repeated synoptic surveys for a suite of chemical and physical variables is recommended. The monitoring program should utilize in situ monitors and automatic samplers in addition to manual sampling methods to achieve a data base for analysis of extremes and trends and for input to water quality models. A water quality model, such as employed in the L'Anguille River Basin, Arkansas, but with the addition of a linked watershed-water quality model to handle land-use effects, is recommended for section 208j investigations.

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WATER QUALITY MONITORING

Frank J. Humenik,
Professor and Associate Department Head, Department of Biological and Agricultural Engineering, N. C. State University at Raleigh

Developing water quality programs and attendant implementation strategies have emphasized needs to develop more cost-effective procedures and programs for stream monitoring and evaluation on an areawide basis. Currently water quality data are generally obtained by various grab or automated sampling procedures and modeling techniques. Grab and automated sampling sites and schedules can be determined on the basis of either professional judgement or statistically-based random selection. Generally, judgemental selection is employed for either grab or automated sampling and data collection for model development and attendant fine tuning.

Judgemental sampling allows selection of particular sites and procedures in response to technical requirements, resource availability, and program needs. However, judgemental selections are subject to bias and cannot be used in extrapolating information to a larger area or sampling universe. The relative advantages and disadvantages of judgemental sampling appear in Table 1.

TABLE 1. JUDGEMENTAL SAMPLING

Advantages	Disadvantages
Professional Judgement	Subject to Bias
Selected Desired Site	Site Specific Information
Select Sampling Schedules	Time Specific Information

Random sampling based upon statistical procedures provides an unbiased selection procedure which can be easily duplicated. Additionally, information received from the sites evaluated can be validly extrapolated to the total sampling universe used for the original selection process. Correspondingly, statistical techniques can be employed in making more meaningful and complete data evaluations, accuracy estimates, and field interpretations. Such statistical evaluation techniques also allow the determination of precision versus cost relationships on the basis of actual field data. Some of the advantages and disadvantages of statistical sampling and analysis techniques appear in Table 2.

TABLE 2. STATISTICAL SAMPLING AND ANALYSIS TECHNIQUES

Advantages	Disadvantages
Mathematically Sound	No Investigator Judgement
Widely Accepted	Subtle Differences Missed
No Investigator Bias	System Interpretation Concerns
Can Reduce Data Needs	Misuse Potential
Illuminate Unsuspected Factors	Special Training Necessary
Can Eliminate Confounding Effects	
Handle Large Data Sets	

Either grab or automated sampling plans can be determined by judgemental or statistical procedures. The relative advantages and disadvantages for grab sampling are presented in Table 3, and for instrumented sampling in Table 4.

TABLE 3. GRAB SAMPLING

Advantages	Disadvantages
Low Equipment Cost	Periodic Data
Cover Many Sites	Human Error or Variation
Easily Change Location	Inconvenient Sampling Times
More Representative Sample	
Quick Sample Return	

In overview, major benefits of judgemental selection for a grab or automated sampling plan would be the ability to select desired sites and sampling schedules based upon given program needs. The major benefits of employing random selection of sampling sites and schedules by statistical methods for either a grab or automated sampling plan are the elimination of bias, method reproducibility, capability for statistical analysis techniques, and the ability to make valid areawide assessments based upon the study of representative portions.

TABLE 4. INSTRUMENTED SAMPLING

Advantages	Disadvantages
Reduce Travel & Labor Costs	High Equipment Costs
Continuous Data Record	Routine Maintenance
- Runoff Events Monitored	Fixed Sampling Point
- No Human Variation	Unpresentative Sample Concern
- Available 24 Hours a Day, All Year	

Statistically-based sampling procedures are well known and have been used in many areas for estimating the total by randomly sampling a portion of the whole. The potential benefits of using such statistically-based random sampling to make areawide water quality assessments makes the examination of this commonly utilized evaluation tool very attractive. As noted, statistical procedures can be used in setting up both grab and instrumented sampling programs. Thus, the employment of statistical sampling would not impact field monitoring techniques but would require additional preparation and work in establishing study sites and sampling schedules. Therefore, statistical sampling concepts could be utilized in concert with existing grab and automated sample procurement procedures.

Cost versus precision relationships for different levels of grab sampling in comparison to automated sampling can also be evaluated by statistical procedures. Therefore, judgements can be made as to the most cost-effective monitoring program for a given need and resource capability. Such precision and cost-effective information has generally not been available to assist water quality planners in making difficult decisions for costly water quality monitoring programs. Items such as the number of sites, sampling technique, sampling frequency, analytical measurements, etc., that would be most appropriate for a given need can be established on a cost-effective basis. Results for such a statistically based precision-cost analysis for a field evaluation of grab and automated sampling programs are presented in the final report for EPA Grant No. R803328, "Pollution From Rural Land Runoff"(1).

Assessment and regulation of sources impacting water quality over an entire river basin are complex problems. The major components that contributed to an understanding of the physical system include (a) relative contribution of point sources and nonpoint sources; (b) impact of land-use activities; (c) effectiveness of best management practices; and (d) cause and effect relationships between measurable water quality parameters and subsequent biological impacts. Results of research conducted to establish monitoring techniques that will help provide technically valid methods to estimate rural nonpoint source nutrient yields and concentrations on an areawide basis by Bliven et al (2) summarize many factors affecting the monitoring of areawide rural water quality. The sample type to be collected is an immediate decision that must be made. Characteristics of composite and discrete sample types are listed in Table 5.

TABLE 5. SAMPLE TYPE

Composite	Discrete
"Describe System"	"Explain System"
Less Analytical Load	Variation Across Events
Mass Yield	Variation In Time
Average Concentration	Peak Concentrations Measured
Extremes Unknown	Necessary For Statistical Analyses

A conjunctive consideration to sample type is sampling frequency and whether samples will be taken based upon time or flow basis. Several details of time versus stage related sampling are presented in Table 6.

TABLE 6. SAMPLE BY TIME OR STAGE

Time	State	Combination
Even Representation Of All Time	More Information On Runoff Events	Combines Best Aspects of Both Techniques
	Less Information On Steady Baseflow	Equipment Must Be Modified
		Generally More Samples

A major consideration that is becoming more commonly recognized is whether water quality evaluation should be made on the basis of concentration or transport. Generally water quality criteria are based upon concentration but no elaboration is made as to whether this concentration represents a short-term or long-term average and what type of variation both in magnitude and frequency would be allowed. It is commonly known that concentration values are much easier to obtain than mass transports or yield which require flow measurements. Flow can be measured by either relatively simple in-stream procedures and natural controls or more elaborate structural devices and continuous stage monitoring. Therefore, the cost of flow measurement required for mass transport or yield calculations must be considered when the cost effectiveness of concentration versus yield information is considered.

It is well known that the majority of constituent transport in receiving streams generally occurs during rainfall-runoff events. Since these types of high water conditions cause concern, particular attention is generally directed to

determining both concentrations and yields during such high flow excursion events. Visual observations and data analyses confirm that over time only a few high flow measurements are recorded resulting in a very skewed flow distribution. Statistical theory states that for such skewed distributions, stratified sampling on the basis of the measured parameter may provide a more precise estimate of the mean at a given sample intensity compared to simple random sampling. In practice a method of stratifying stream measurements based upon flow regime is required. A method of employing daily weather predictions as a means of time stratification to improve yield estimate precision at a given grab sampling intensity has been reported by Bliven et al (2). Some of the advantages and disadvantages of such rainfall probability stratified sampling are indicated in Table 7.

TABLE 7. RAINFALL PROBABILITY STRATIFICATION

Advantages	Disadvantages
Better Evaluation of Runoff Conditions	Continous Weather Monitoring Required
Improved Resource Allocation	Short Time Notification For Field Crew
	Sampling Trips May Not Yield Samples

Consistent with sampling theory, results from field monitoring verify that increased estimate precision for both water and constituent yield can be obtained by sample stratification on rainfall runoff probability. Thus, employing daily weather predictions as a means of time stratification to improve water yield estimate precision for a given grab sampling program should be considered. However, continuous stream stage records would be required in conjunction with such grab sampling for constituent concentrations to obtain precise yield estimates. Thus, the monitoring and evaluation of water and constituent yields or transport is a difficult and costly measurement even with employment of analytical tools such as sampling stratification on high flow events by employing daily rainfall probability predictions, computation of long-term average nutrient transport by flow duration curve techniques, or other analysis techniques, or other analysis techniques.

The assessment of various inputs on water quality is a very important consideration in the design of an evaluation plan and specific monitoring guidelines. The nature and impact of rural stream inputs on water quality as determined by a comprehensive field evaluation of such judgemental and statistical procedures for grab and instrumented sampling have been reported by Humenik et al (3). The portion of the basin designated as the study area was stratified on the basis of soil-topographic-land use factors resulting in statistical coverage of about 25 percent of the 4943 mi^2 basin. From the four designated strata, 15 subbasins were randomly selected for stratified random grab sampling. Four of these sites were also instrumented for automated sampling. Additionally, a 20-mile stream reach which included one of these statistical sites was monitored to evaluate parameter changes with distance and to examine the relative magnitude of point and nonpoint inputs.
Assessment of point and nonpoint source impacts in the stream reach substudy verified classic point source concentration spikes with subsequent declines to intermediate levels for all investigated constituents except chloride and

nitrate. Therefore, for the studied stream reach nitrogen and phosphorus inputs which appear to come from treatment plant effluents are reduced to headwater background levels as long as the stream assimilatory capacity is not overwhelmed or natural inputs result in a changed background water quality. The relatively similar arithmetic average concentrations for the 15 statistically selected sampling sites throughout the basin which received rural inputs from different land-use and geoclimatic regions including areas with over 90 percent forested, and in the main river draining these sites, indicate that more data on background conditions and relative impact of nonpoint sources are needed before widespread implementation of best management practices is required, particularly in areas with heterogeneous land use.

Developing regulatory criteria should be responsive to ambient conditions and not entertain standards requiring better than background water quality, particularly for relatively undisturbed or pristine areas such as occurred for total phosphorus at several forested sites which were among the 15 statistically selected sampling sites in the previously referenced field study. It also seems most important that national guidelines be developed for water quality monitoring and evaluation so that such increasingly important activities can be compatible and based upon the most updated and technically sound information available from all relevant discipline areas. National guidelines for water quality monitoring and evaluation of nonpoint sources would greatly facilitate development and implementation of sampling programs that could be tailored to specific needs but yet be conducted to provide a common core of critical data supportive of an overall national evaluation strategy.

In conclusion, virtually all sampling programs and procedures have relative advantages and disadvantages as emphasized in the discussion of just a few alternative water quality monitoring techniques. Thus, decisions have to be made concerning the best technologies for a given water quality monitoring and evaluation need. Correspondingly, it becomes most important to understand the basic principles of alternative sampling program designs and actual monitoring techniques. Technically sound national guidelines that would help monitoring and evaluation programs take full advantage of available information, and would compatibly address national needs while allowing sufficient flexibility for local conditions would seem to be both appropriate and critically needed. There are two major directives to recognize in water quality monitoring: alternative techniques exist and each sampling program should be individually tailored to meet a specific need and resource capability.

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WATER QUALITY MODELS

by

ROBERT SWANK, EPA, Athens, Georgia

I would like to discuss my philosophy of modeling in relation to the problem of selecting BMP's and monitoring changes in water quality. How do we design models? What is involved? How are models used? What are models good for? How will models help us in making decisions? Decision making is really the foundation; we can have our philosophies, but decisions depend a great deal on both objective information and professional judgement.

Several series of models exist to apply in seeking solutions to various problems, but difficulties arise in matching models and problems. Modeling is not a new concept in water management for making decisions relative to water problems, since models have been around for about 90 years. We have been modeling a long time in order to understand various kinds of water problems. Water quality modeling efforts begun around 1920 were concerned with the dissolved oxygen sag in the Ohio River resulting from the discharge of both treated and untreated sewage. Water quality concerns grew to include changes in temperature profiles as a result of power-plant discharge of cooling water. The more recent efforts in the 208 planning process have recognized the need to improve modeling activities. They are the first efforts to incorporate modeling with regard to nonpoint sources of pollution. Impacts of pollutants on water users are of interest along with the impacts on the quality of receiving waters.

During the course of the past 50 years, millions of dollars have been invested in modeling studies. Water quality modeling is not a new field of study, but a new area of application. Its use in agriculture will help in understanding nonpoint source pollutants and their relationship to water quality.

There are no universal models, even though models have been used for a long time. However, there is a general feeling that models "help" in making decisions on control strategies. I use the word "help" because modeling is useful in organizing our thoughts, ranking alternatives, and making cost estimates. Even so, there is a kind of uneasiness with the use of models.

Why do we feel uneasy about the use of models? For one thing, there are few studies on the use of models and their reliability. Are we modeling the right processes and are we looking at the right pollutants? Are we studying each situation long enough to learn that a small statistical subsample over the long haul will not provide useful results, where as, over the short run results look pretty good. So we are really uneasy. There is a shortage of good data and a sufficient number of studies haven't really been carried out to verify the models in a statistical or quantitative sense. More important than uneasiness about models themselves is an uneasiness about the soundness of decisions based on the use of the model. There are no studies where decisions based upon modeling results were implemented.

Advances in applying modern computer technology to planning under the 208 process have important implications for the use of models for water quality planning purposes. Models are becoming more complex, not simpler, and computers are needed to handle several different kinds of problems. We have taken full advantage of the capability provided by computers. We are pioneers in studying the cause-effect relationships between agriculture nonpoint pollutants and impacts on water quality. This work requires complex models involving complex computations.

There are two parts to the way models can be used to interact with water quality problems. The first part involves the interaction between models and the people who use them. The second part involves the interaction between modelers and the users of modeling results. The user of a model is seldom the user of modeling results. Why is that the case? The operator or modeler putting information in and taking it out, would usually be an engineer or scientist. The person using the model results is likely to be a manager, planner or columnist; he may even be a politician.

It is useful to know the priorities of individuals using a model. With respect to modeling, what is the engineer's or scientist's interest regarding the model he is using?

It may be important to know how accurate it is. Are the outputs scientifically defensible? Are we modeling the right processes? Is the model calibrated, verified, and documented: Is it state-of-the-art? Does it reflect my prejudices?

A manager cares little about the model itself. He wants it to be flexible enough to do the kinds of things he wants done, and to analyze the kinds of scenarios he specifies. His questions involve what can be analyzed and whether the model output makes political sense. He wants dollars and cents output and cares little if it is accurate, scientific, or documented.

What about jargon and the difficulty of setting up the problem for the model. The engineer will probably use the kind of jargon I use if I were fully unrestrained. The manager's language will be polished, political, and economic.

Hopefully, you get the picture of what I have attempted to outline. There is often a large communication gap between the modeler who is developing and running the model, and the manager who has the task of making decisions based upon the output of the model. Problems often arise when the decision makers must specify the input to the machine and the problems he wants to analyze. Tension always exists with the application of a model.

Another problem is the interaction of the model capability and the problem to be solved. The generic solution approach or the generic selection of BMP's is typically used. What does the generic selection of BMP's mean? Based on experience, practices are selected to minimize the quantity of pollutants that come off the land all at the same time. By the time all pollutants are under control there may be 57 different practices going on the land and all in the same watershed. When we control everything in parallel, we know very little about the water quality impacts. This is what I call the generic approach to BMP selection.

The use of models is an alternative to generic solution approach. However, models are only potentially useful. Suppose there are 10 agricultural management practices to consider in a watershed, and we consider them 4 at

a time for four pollutants to estimate the cost of each option in order to determine the most effective and least cost option. This might require 1,000 calculations because of the large number of combinations. The model helps in the calculations.

Now let us make a rational engineering assessment of the problem by taking into account monitoring, data, modeling capabilities and the problem setting; namely, the watershed with some downstream water. Key to the analysis is to somewhere pick the critical pollutants which will require problem analysis before searching for a solution. Monitoring data will indicate the nature of the problem and will estimate the prime impacts on existing water quality. Water quality data, impacts of various pollutants on the receiving water and practices will be used to make a critical pollutant list. The analysis will provide a basis for deciding whether the problem is phosphorus, nitrogen, pesticide, sediment, or some combination of the above.

Even in the engineering assessment the model used is optional. There may be sufficient monitoring data to decide on the critical pollutants or someone downstream may have analyzed water quality. In short, some guidance on the problem at the start and a model component is needed to identify solutions.

The key issue is using the most effective combination of monitoring and modeling to provide flexibility to achieve effective design or control strategy that is near optimal for critical pollutants. Modeling forces the user to analyze the quality impacts on a real piece of ground. The process can be complex, and its success depends on the objectives and availability of resources.

Model development is moving in the direction of systems development of point and nonpoint source problems. Appropriate water quality scenarios may be required to analyze problems. A systems approach requires more pollutant information, water quality data, and impact data. The system incorporates point sources vs. nonpoint sources and pesticides vs. nutrients. A complete view of the system is needed from the watershed all the way down to critical areas. This forces the modeler to look at land, upland streams, rivers and lakes. The system is complex and the model components have to be compatible.

I have a question on the use of modeling. Will I gain for the high level of sophistication? In general, there are useful gains. The system can analyze pollutants and the cost to control each of the pollutants. It can examine the issue of equity for point vs. nonpoint and cost-effective point vs. cost-effective nonpoint. The system can identify who pays and who benefits. This is useful information to managers.

I have a systems view of the world. The systems approach is costly, but it is the way the real world is moving, technologically. With the systems view of the world, a look at nonstructural controls is a little more easily carried out, including such difficult things as timing of pesticides applications and use of fertilizers.

A key feature in both the systems approach and the simpler modeling approach is the critical source reduction approach that allows you to extrapolate existing monitoring data. The critical source reduction method requires some water quality data to start. This includes monitoring results, as well as criteria upon which to base the identification of critical pollutants and critical areas. You can then use separate components or a systems model to get a near optimal design based upon water quality goals.

What about selecting the right models? A large number of models can be used to simulate the interaction of hydrologic parameters and activities on the land surface. The interactions are important and impact a lot of features that affect the model's usefulness for doing things like BMP assessments or water quality impacts. You will hear speakers at the work sessions discuss lump parameter models, distributed parameter stochastic models, and others who characterize the hydrology component used to generate the hydrographs in loading models or watershed models. You will also hear about the routing of waters in receiving streams.

Now these aspects in themselves are not too important, but I wanted to introduce the terms. The next classification is significant because it affects the way we look at pollutants that are of interest. For example, an important physical process the model attempts to represent relates to total erosion or quantity of material discharged from the land's surface and the ways it is routed after reaching the stream. There are several methods for material routing. For example, we can do sediment routing by particle size class if we are clever enough. People in this room are developing models that respond to this need.

What about chemical pollutants and sediment interaction in the water or even on the land surface? We know that pollutants go on and off sediment. Models are needed to deal with the materials that are soluble on sediment, either on the land or in the stream. There is a problem of pollutant involution when a pollutant on the ground goes into the air or in the water and is stripped. The problem of aeration may affect the oxygen level in the stream or reaction between pollutants, because we know that pollutants react. Place a pesticide on a piece of ground and a variety of chemical reactions occur in relation to the temperature, water, and soil. It is useful to model these relationships.

The same thing is true of the instream component. Many kinds of reactions, such as hydrolysis, pathology, reduction, oxygenation occur. Biologically, bacteria degradation takes place. Carbon and nitrogen oxygenation by bacteria produce an oxygen sag and other physical and chemical effects.

The features of a model affect the kinds of questions users may ask. Single models are available. Multiple models require a water balance when solutions are generated. There are steady state and simplified steady state models. A "yearly average load in a watershed" model gives monthly average water and sediment yields, but the model provides little information on the impact, following a single storm event, of a soluble pesticide on the receiving stream. The model features affect questions asked, and indeed, the kinds of BMP's we can analyze with that model.

You have geographical resolution such as a five acre field, a 200 acre farm, or 200 square mile watershed. The same is true of instream aspects such as a farm pond, a reach of the Missouri River, or the Great Lakes. The scale must weigh the problem that is being analyzed. Also there may be an ecological component such as trophic level, predator prey relationships or food chain. Thus, there is a variety of features that can be used to classify models. Other considerations include the cost of a model and the kinds of inputs required. These features have to be taken into account when choosing the model or modeling approach to solve specific problems.

The key element in using models in BMP selection is to adequately define the water quality problem. Current problems may be the easiest to identify and solve. A more difficult problem is to forsee future water quality problems. We often look for future problems using other people's data and modeling. Suppose a drinking water reservoir becomes eutrophic. It may require a sophisicated ecological model of the lake to determine why it is becoming eutrophic and what the researchable limits of the various carbon and nitrogen loads are. With this information the question of adequate control of point and nonpoint sources can be analyzed and identified.

Assessment of the water quality problem and critical pollutants can be used to place bounds on the problem. Water quality criteria and the expected use of the water body, such as for drinking, recreation and other uses target our allowable concentration levels for the pollutants. This will give design and load requirements that are appropriate for the expected use. This information is needed to identify and relate BMP's to water quality objectives as required. Then the appropriate BMP solution approach is selected, such as generic, critical resource pollution reduction, or simultaneous optimization of all the pollutants chosen from the previous analysis. That selection will have to be based on our own assessment of our resources and data requirements. Within the context of funds and data, it is possible to select the modeler, the pollutants, and the design strategy. Scenarios are written and calculations are made to develop various plans, cost them out and ask which of the above strategies are either the most politically and/or economically feasible. Pick those and you have, by definition, defined BMP's. That all sounds very easy. Modeling plays a role. It won't do it by itself and neither will a lot of other things.

Hopefully, these tips will make BMP selection a little easier by matching as closely as possible the model characteristics, pollutants and strategy for the water quality problem. Remember that no one model is applicable for all pollutants or problems that are to be addressed in selecting BMP's. Some problems may easily be handled by several models. In that case, make it easy on yourself by taking the one with which you are most comfortable. Choose the cheapest model that makes you happy. Some of the problems you identify may not be covered by any of the models on the drawing board now. If that happens, you or you mechanic will have to cut and paste as best you can or hope that somebody in USDA or EPA will listen to your plea for help and give you a hand. That's approximately where we are in the modeling business.

WATER QUALITY MODELING - ECONOMIC COMPONENTS AND EVALUATION

ROBERT B. McKUSICK, Vice President, Northwest Economic Associates, Vancouver, Washington

INTRODUCTION

Is it possible to measure the impacts of water quality and conservation programs, projects, and practices? 1/ Do models exist that could be used to measure such impacts and tradeoffs? These are the two questions that the Monitoring and Modeling Workshop Program Committee asked me to address today. In order to answer these questions, it might be helpful to first review why there is a need for water quality and conservation evaluation and then discuss economic parameters and data needs, scope of analysis and study area, and economic models and related analytical systems.

PROGRAM AND PROJECT EVALUATION

Federal agencies involved with land and water conservation, and water quality, are required to do an impact analysis of proposed programs and projects. Special evaluations are requested frequently by the White House, OMB, and the Secretary of Agriculture. Examples of such requests include the Agricultural Conservation Program study and the 160-acre limitation study.

Congress has also mandated program evaluation. The National Environmental Policy Act of 1969 states that all agencies of the Federal Government shall "utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and decision making which may have an impact on man's environment. . ." The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) and the Soil and Water Resources Conservation Act of 1977 (RCA) both require program and project evaluation. The 1977 RCA directs the Secretary of Agriculture to provide Congress and the public with periodic evaluations and appraisals of the Nation's agricultural resource base and its relationship to USDA land and water conservation programs. The 1977 Clean Water Act and the Culver Amendment also require an evaluation of the effectiveness of water quality best management practices (BMP).

These mandated program evaluations have been initiated: (1) USDA/EPA Rural Clean Water Program and Model Implementation Program; and (2) USDA Land and Water Conservation Program Evaluation. Besides mandated program evaluations, research is ongoing which supports information needs for evaluations. For example, the Environmental Protection Agency (EPA) is funding research to evaluate the cost effectiveness of BMP. This work is currently in progress at Cornell University for nonirrigated areas and University of California, Davis, for irrigated areas.

1/ For simplicity in this paper, I will refer to water quality and conservation evaluation to mean evaluation of programs, projects and practices.

From the standpoint of economic analysis, these mandated evaluations and related research are requesting the same information:

1. What is the adequacy of the resource base, in relationship to resources problems of conservation and water quality, to meet food and fiber demands and environmental enhancement requirements?

2. How effective are land and water conservation and water quality programs, projects, and practices?
3. What are the costs and benefits of conservation and water quality practices?

4. What institutional arrangements, incentives, and strategies exist and are needed to implement conservation and water quality practices?

A logical starting point for a conceptual economic framework for evaluation is the Water Resources Council's "Principles and Standards." Even though these are planning "principles" and "standards," the same information and data needs for ex ante planning are also needed for ex post evaluation. In the ex ante analysis researchers use estimates of what might or ought to happen. In the ex post evaluation analysis, researchers use data which measures what actually happened.

The "Principles and Standards" establish a set of criteria, objectives, and accounts to follow in measuring economic, social, and environmental impacts for evaluation analysis. This procedure has been reviewed, tested and used by Federal agencies for water and related land resource planning.

ECONOMIC PARAMETERS AND DATA NEEDS

Water quality modeling and evaluation requires that both physical and economic impacts be measured. Economic impacts should include:

1. Direct benefits and costs (e.g., employment, income, value of output, cost, and net returns) of both "with" and "without" changes in water quality, and land and water use.

2. Indirect benefits and costs under the same conditions (e.g., changes in sales and purchases, income, and employment of support industries).

3. Administrative costs to implement and enforce water quality and conservation measures.

4. Distribution of benefits amd costs (e.g., who pays and who benefits).

At present, lack of data on the effectiveness of evaluating water quality and conservation measures creates the greatest void. Traditional analyses of project effectiveness have been based on such measures as miles of terraces, acres of protected watersheds, and number of projects. Analysis of the physical and economic impact of implementing practices has been ignored, including such measures as improvements in water quality; tons of soil saved; and economic impacts on income, employment, costs, returns, farm size, and structure. Many of these analyses require monitoring of the impacted area to observe changes over time. If a monitoring system is developed, it is important to provide information about producers' and landowners' reactions to alternative land and water conservation practice adoption incentives.

River basin and watershed studies have developed significant data and information bases. This information can serve as a starting point (base line data) from which to measure changes in water quality and land and water use. Such information includes land and water suitability and availability; ground and surface water supplies; yields, prices, costs, and production relationships; resource base inventories, classifications, and assessments; characteristics of resource owners; and soil erosion rates and sedimentation.

SCOPE OF ANALYSIS AND STUDY AREA

Water quality evaluation and land-water conservation practice should be analyzed as part of the total process of agricultural production, processing, marketing, transportation, and resource allocation. Each one of these components has traditionally been analyzed assuming production did not involve a "quality" or "conservation" dimension. What is needed is to add this new dimension to the traditional production analysis.

If we consider water quality and conservation as one component of a bigger production process, then the scope of analysis and the study area can be defined more clearly. I hypothesize that the appropriate study area is the "region," which includes a major river basin and appropriate watersheds, a receiving lake, if one exists, and regional and national markets for products from the region. Both hydrologic and economic variables have to be considered; in particular, the interaction of these variables.

At the national level, programs and policies that directly influence the region include cost-sharing (grower production costs), commodity price supports and acreage allotments, and regulation of resource use. At the watershed level, changes in land and water use impact surface and subsurface water quantity and quality.

It is at the "regional" level where the national programs, policies, and markets interact with the hydrology and land use of the watershed and river basin. The challenge to the modelers and other people doing water quality evaluation is to incorporate enough detail in the regional model to account for the uniqueness of the region (production, marketing, processing, transportation, institutions); national program policies, and markets; and watershed hydrology. These models have to be usable within the time allocated for a study.

ECONOMIC MODELS AND RELATED ANALYTICAL SYSTEMS

Numerous models at the regional level could be adapted for water quality and land and water conservation evaluation. At the river basin level, linear programming models (both cost minimization and profit maximization) exist for many regions throughout the U.S. These models analyze production activities and land and water use and develop inputs for the national economic development and regional economic development accounts, as specified in the "Principles and Standards."

River basin models assume the region is the decision unit. Data inputs include short-run production relationships (commodity yields related to production activities); resource availabilities; commodity costs, prices, and yields; and acreage and production levels. These models have traditionally determined long-run (10-20 years) resource use based on commodity demand projections. The river basin models could be adapted to include both quality and conservation at the production level. Production activities would have to reflect either reduced or increased resource use, yields and costs associated

with changes in water quality and land and water conservation.

There are also numerous regional input-output models which have been developed as part of river basin studies and watershed/RC&D research. These models give both inter- and intra-industry tradeflows. They can also measure secondary impacts of output, income, and employment related to changes in total gross output.

A few models have combined both the linear programming model of production activities and land and water use with a hydrologic model of surface and subsurface water flows. The work at Univeristy of California, Davis, by Horner and Dudek has developed a physical-economic evaluation system for BMP in irrigated areas. Using a simulation framework, these researchers have linked a linear programming model, which estimates land and water use, to a hydrologic model which includes water quality variables. This simulation system involves four models--projections, water quality, land use, and resource production.

The demand for regional commodity production is projected from estimates of changes in population, income, per capita consumption, and U.S. trade policies. The production model determines the amount of land, water, and other productive inputs required to achieve the projected level of commodity demand. The production model includes activities for water quality BMP, and land and water conservation practices. Thus, land and water use decisions can be incorporated directly into the model. The specific location of commodity production and resource use (by watershed) is determined by the water quality model and the quality and quantity of irrigation return flows. BMP's that impact hydrologic relationships can also be included in the water quality model.

The challenge to the modelers is to link economic land and water use models to the hydrologic water quantity and quality models. The work at UCD is definitely a step in the right direction. Specific economic and hydrologic models do exist, but what is needed is:

1. A systems approach to link physical hydrological models with economic land and water use models.

2. The inclusion of quality and conservation data and relationships in these models.

3. A sensitivity analysis of the aggregation of data and production activities to determine how much detail is needed in regional models.

CONCLUSIONS

There will be water quality and conservation evaluation. The law requires evaluations, the Executive Branch and Congress are requesting evaluations, and Federal programs are set up for evaluations. Researchers, modelers, and other analysts must develop and adapt techniques to quantify the impacts of these practices, projects, and programs.

The criteria for evaluation are extremely important. The "Principles and Standards" are a logical starting point for these criteria and provide a methodology to quantify national, regional, social, and environmental impacts. Even though the "Principles and Standards" are an ex ante planning methodology, the same concepts, criteria, and tradeoffs can be applied to ex post evaluation. In general, only the absolute levels of the data will differ.

The "region" appears to be the appropriate study area. The regional analysis

has to reflect national markets, programs, and policies, but must also recognize unique hydrologic characteristics of the river basin/watershed.

Both regional economic and hydrologic models exist. What is needed is the linking of these models in an interactive framework so that resource policies and practices directly influence land and water use and water quality. There are a few ongoing research projects, such as the work at University of California, which are linking these models in an interactive framework. This work should continue, but the sensitivity of the results should be tested as to the degree of data aggregation. These models have a tendency to get large and data consumptive. Whenever possible, the productive activities should be aggregated, if there is not a significant impact on the results.

Researchers and modelers cannot wait for data from water quality monitoring. Existing models and systems can be modified when these data become available. For now, the best estimate of how land and water use changes impact water quality should be used.

LAND AND WATER RESOURCES AND ECONOMIC MODELING SYSTEM: A Conceptual System of Models and Data for Evaluation of Conservation Policies, Programs, and Practices*

Reuben Weisz, NRED/ERS, USDA

INTRODUCTION

This report presents an analytical blueprint for a Land and Water Resources and Economic Modeling System (LAWREMS) to be used as an aid in evaluating the U.S. Department of Agriculture's land and water conservation programs.

The LAWREMS concept was formulated in response to a request from the Senate Committee on Agriculture, Nutrition, and Forestry to develop a comprehensive evaluation capability for conservation programs. Therefore, this report first outlines some of the Executive and Congressional directives that prompted its development. Chapter II sets forth a conceptual framework for LAWREMS, illustrating its potential service role in the impact analysis and program evaluation processes. Chapter III describes LAWREMS as it now exists, focusing on the Directory of data and models, user methods for evaluating those data and models, and alternative methods of accessing them. The report concludes by presenting options for continuing LAWREMS as a permanent activity.

Executive and Congressional Directives

Historically, government agencies have been asked to identify and evaluate the effects of existing programs. These special program evaluations are requested frequently by the White House, OMB, the Secretary, and Congress. Examples are the current Agricultural Conservation Program study and the 160-acre limitation study requested by the Secretary.

In addition, all government agencies are now required to undertake analyses of expected impacts of proposed actions. The National Environmental Policy Act of 1969 states that all agencies of the federal government shall "...utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and decision-making which may have an impact on man's environment...." This view is also reflected in the letter and spirit of the Forest and Rangeland Renewable Resources Conservation Act of 1977 (RPA), a precursor to the Soil and Water Resources Conservation Act of 1977 (RCA).

The 1977 RCA directs the Secretary of Agriculture to provide Congress and the public with periodic evaluations and appraisals of the nation's agricultural resource base and its relationship to USDA land and water conservation programs. The Act states that the:

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* This report was prepared by Paul Dyke, Linda Hagen, Reuben Weisz, Melvin Cotner, and Howard Hogg of the Economics Research Service, U.S. Department of Agriculture.

"...Secretary shall establish an integrated system capable of using combinations of resource data to determine the quality and capabilities for alternative uses of the resource base and to identify areas of local, State, and National concerns and related roles pertaining to soil and water conservation, resource use and development, and environmental improvement."

Land and Water Conservation Task Force

Prior to the enactment of the Soil and Water Resources Conservation Act, the Senate Committee on Agriculture, Nutrition, and Forestry in December 1976 requested USDA assistance in evaluating the Department's land and water conservation programs. The committee specified the following four basic purposes for the evaluation:

1. To assess the extent to which program and legislative purposes are being met;

2. To assess the impact of the programs within the broad context of national conservation policy and needs;

3. To determine whether the programs are being administered efficiently;

4. To determine whether the program purposes and mechanisms remain valid in the context of current and projected conservation needs.

A USDA Land and Water Conservation Task Force was appointed to carry out this evaluation. The Task Force established a team to prepare an Initial Report of existing information pertinent to an evaluation of USDA land and water conservation programs. This team's report was forwarded to the Senate in December of 1977. The Task Force also identified the following additional areas of study and established a team to carry out each one.

(1) The Land and Water Conservation Overview (Overview Team).--to provide an overview of the present physical, social, and institutional setting for these programs.

(2) Evaluation of USDA Programs (Evaluation Team).--to initiate evaluation of selected programs and to develop a plan for a continuing evaluation system.

(3) Impacts of Land and Water Conservation Practices and Management (Impact Team).--to determine the effectiveness and efficiency of installed conservation practices in meeting intended objectives.

(4) Interagency Modeling Team (LAWREMS Team).--to study the need for development and maintenance of a Land and Water Resources and Economic Modeling System (LAWREMS).

The charge to the LAWREMS Team was to 1) develop an information system about current data and analytical capabilities within the Department; 2) outline a conceptual framework for an ideal LAWREMS; and 3) recommend a future course of action for LAWREMS. The present paper summarizes the activities of the LAWREMS team.

The LAWREMS team initially separated its work into two parts. Phase I, which has been completed, included the initial inventory of existing models and data systems. Those selected are documented in the LAWREMS Directory which is designed to provide easy identification of the data sets and models through a keyword index. A conceptual system for an integrated effort to provide analytic support for evaluations was developed, and recommendations for implementation were made. If approved, Phase II would basically call for maintenance of the Directory and would provide access to some of the systems contained in it. Depending upon the level of commitment to the LAWREMS approach, a more extensive implementation of the conceptual system could be achieved.

CONCEPTUAL FRAMEWORK FOR LAWREMS

The principal role to be performed by a LAWREMS effort is one of integration. LAWREMS conceptually should assist the evaluation efforts within the Department by bringing together and making available data and analytic systems to improve capabilities for assessment of the effectiveness of land and water conservation programs.

In a general sense, LAWREMS should provide three related services:

1. Communication.--LAWREMS should promote cooperation among USDA agencies, other Federal and State government institutions and private research groups by providing information on the uses, limitations, and linkages among existing models and data. As an information service, the LAWREMS Directory should provide a means for program evaluators, impact analysts, and researchers to find out what data are available within the Department and, to some extent, elsewhere. Once analysts and evaluators define their problems and procedures, a search through the LAWREMS Directory would reveal existing models which are compatible with their needs. The latest in models and methods should be included. In cases where models are not strictly appropriate, the methodology may be applicable to the problem at hand. The system should, therefore, prevent redundancies in data collection and duplication in model development, thus reducing costs. Existing gaps would be identified if the Directory search yielded nothing relevant.

The LAWREMS staff should aid in identifying data needs and gaps. However, formulation of a checklist of data needs and gaps prior to the systematic specification of the problem would be a fruitless endeavor, and was, therefore, not attempted by the LAWREMS team. Data requirements are defined by the problem to be studied and the procedure used. For example, erosion data may be available by river basin and major land resource areas, but not available by state. If the study is to be carried out at the state level, then adjustments to the data must be made, indicating a gap. Since data is available in two forms, it could also be viewed as a duplication. A more difficult problem arises, however, when data is available only at the

national or regional level and must be disaggregated to the state level, for instance. Aggregation and disaggregation of data creates statistical reliability problems which necessitate collection of new data at the required geographical level.

2. Coordination.--LAWREMS should help coordinate studies where more than one agency or department is involved. For instance, LAWREMS could help integrate evaluations of the several agencies that have programs and research on erosion. In cases which require an interdisciplinary approach, such as regional land-use studies, the LAWREMS coordinating and integrating mechanism could be useful. For instance, an economist studying land-use could utilize LAWREMS to identify, locate, and gain access to data and models on the subject areas with which he is relatively unfamiliar, such as the region's weather, soils, hydrology, etc. He could then make contact with specialists in those fields, resulting, hopefully, in more valid analyses.

When information is not available, applicable or directly accessible from existing sources, the LAWREMS staff would help coordinate and assist agency efforts in designing new models or modifying existing ones, along with identifying data requirements. In most cases the actual model building or modification would be done by the agency controlling the model, thus capitalizing on its expertise.

3. Access to Information.-Too often in the past, models and data sets have been developed for a special purpose or need, and then have been shelved. Too little attention has been devoted to encouraging, facilitating, maintaining, and promoting the use of existing systems. A major purpose of the LAWREMS activity should be to promote interagency and Congressional access to existing systems. "Spinoff" benefits should include promoting intraagency access to models as well as enhancing the ability of nonfederal researchers (in State and local government, academia, and the private sector) to make use of existing systems. The basic maintenance and control of data and analytic capabilities in LAWREMS should remain, however, with the developer.

Policy and Program Development Steps

The land and water conservation program development process involves the identification of goals, policies, programs, practices, and procedures for utilizing and conserving natural resources. The Department of Agriculture and Congress are expected to operate in such a way that the nation's policies and programs bring about the effective and efficient use of our nation's agricultural resources over time. These activities and decisions should be consistent with the letter and spirit of laws, directives, external constraints, current public inputs, long-range needs, and the capabilities of the nation's resource base. This indicates a need for a comprehensive approach throughout the land and water conservation program planning and implementation process. The LAWREMS activity would promote this approach by making information available and by encouraging contact and cooperation among analysts.

Policies and programs normally are developed to solve problems. One of the first activities in policy development is to define the problem in understandable terms so others can appreciate the need for a solution. In the process of considering alternative solutions to the problem, the policymaker usually identifies the goal or ideal for the problem situation (see Figure 1, Column 1). The goals guide the alternative solutions considered and ultimately will influence the program features. Finally, most policymakers are interested in the outcome of their policy and wish to evaluate the effects of the programs that reflect the policy.

The Policy and Program Development steps discussed above are simplified. Some of these steps may be omitted or bypassed. In some instances steps are bypassed because data and analytic systems are not readily available to aid the policymaker.

Data and Analytic System Needs

Analytic system capability can be useful at each of the policy and program development steps. One of the principal ways of defining a problem is to monitor the condition associated with the problem over time. An example is the USDA Conservation Needs Inventory. The 1958 and 1967 inventories indicated change in the resource base over the 8-year period permitting an assessment of soil erosion problems between the two periods. The periodic timber survey and the soil survey are other examples of monitoring systems. Similar inventories of conservation investments, disinvestments, resource productivity, land ownership patterns and availability are needed periodically to measure changes in status and identify resource problems. LAWREMS includes the inventory and descriptive systems mentioned above, and others that are useful in defining land and water conservation program needs (see Figure 1, Column 2).

The development of information on goals and objectives also requires systematic analyses, including studies of public preferences and goals. These analyses aid the policymaker in determining program needs and objectives. Analytic systems are used not only to assist in this assessment of public attitudes and preferences, but also to assist in the analysis and projection of trends in resource use and needs to serve future population levels. Examples are the national water assessment system and the national interregional agricultural projection system. These systems permit the estimation of future food and fiber needs by applying per capita consumption rates, export levels, and other factors to projected population levels. While different estimating procedures would be used, similar need analyses can be undertaken on other resource issues such as soil protection, water quality, wilderness areas, reclamation, etc. The LAWREMS system includes models, and associated data, designed to analyze these types of needs and resource issues. (See Table 1 for examples of problem areas where needs analysis would be appropriate.)

Alternatives analysis has become increasingly important as a result of the Water Resources Council Planning Act of 1965 and the National Environmental Policy Act of 1969. Both of these Acts require the examination of alternatives in planning federal projects and in designing them to reduce environmental impacts. Alternatives analysis usually compares the expected effects of two or more approaches to solve a problem. The effects can be in terms

Figure 1. Policy and Program Development Steps and Analytic Needs

STEPS	DATA AND ANALYTIC NEEDS
1. Problem Definition	Monitoring Systems
2. Statement of Goals and Objectives	Social Goals and Needs Analyses
3. Identify Alternative Solutions	Alternatives Analysis
4. Analyze Alternatives	Impact Analyses
5. Implement Program	Physical
	Biological
6. Evaluate Program	Socio-Economic

Table 1. SOCIAL GOALS AND NEEDS (Examples)

I. Soil

  A. Protection (sustained use)
  B. Reclamation (renewed use)

II. Water

  A. Quality
  B. Supply
  C. Flood protection

III. Air Quality

IV. Fish and Wildlife

  A. Habitat
  B. Endangered species

V. Recreation and Wilderness

VI. Waste Management

  A. Disposal
  B. Recycling

VII. Economic Development

  A. Production (food, fiber, forest products)
  B. Employment
  C. Inflation
  D. Rural development
  E. Spatial distribution of production and incomes

VIII. Energy

of physical impacts and biological change as well as differences in social parameters. Some alternatives assessments simply look at the effects of a single program feature; in these instances the comparison is between situations "with" and "without" the particular feature. The results of alternatives analysis prior to the decision about a program provide information for later use in comparing planned effects with actual effects. An example of alternatives analysis would be a comparison between structural and nonstructural measures to achieve sediment reduction.

As implied above, impact evaluation systems measure the actual physical, biological, and socio-economic effects of a policy, program, or practice. The impact on income and distribution of income is often an important effect. Impact analyses address questions like, "What difference did the program make? Was the planned effect realized?" For example, conservation tillage practices should be analyzed to determine their actual effects on sediment movement, crop productivity, and the economic well-being of the farmland owner. Similarly, soil and water loans to individuals could be studied to determine if they provide incentive for adopting desired practices. The LAWREMS directory includes analytical systems which address these questions.

None of the analytic categories described above is all inclusive. Alternatives analysis may be useful in defining the problem. Program evaluations provide useful background for analyzing the possible effects of new programs with similar options or alternatives. Data and monitoring systems are important to all phases of analysis.

Program Structure and Analytic Needs

Program planners are confronted with many choices in designing a program to accomplish a mission for public goals. (See Figure 2). The program development and implementation process can be viewed in terms of an input-output matrix. Certain program features and practices combine to produce different outputs and levels of performance. The land and water programs within the Department are highly interdependent. For instance, soil and water loan programs, as well as the conservation operation programs, are integral inputs for the accomplishment of conservation objectives. In a similar manner the research programs of the Department provide information in support of the conservation programs of the Department. These interrelated programs should be evaluated in terms of their mutual role. Information, models, and data on the 29 land and water conservation programs of the Department should be covered by LAWREMS. These programs encompass 16 functional objectives, such as irrigation, timber, fish habitat, etc. See Tables 2 and 3 for a more complete listing of programs, functional objectives, and subobjectives. (Table 3 is a modified version of the Impact Team's Delphi study results.) Practices can be grouped into two categories--structural (construction) and nonstructural (management and operations) (Table 4). Performance indicators are quantifiable physical, biological, social, and economic measurements. As defined by the Program Evaluation Team, "performance indicators must be able to measure the effects of program activities in achieving the objective(s) of the program. In general, such indicators will provide a 'before and after' or 'with and without' view of an effect of a program." See Table 5 for examples of performance indicators associated with conservation subobjectives. This table is a modified version of the Program Evaluation Team's formulation.

Table 2. USDA LAND AND WATER CONSERVATION PROGRAMS

I. Agricultural Stabilization and Conservation Service

- A. Agricultural Conservation Program
- B. Water Bank Program
- C. Emergency Conservation Measures

II. Economics, Statistics, and Cooperatives Service (formerly Economic Research Service, Statistical Reporting Service, and Cooperative State Research Service)

- A. Resource Economic Research
- B. River Basin Planning Assistance
- C. Production and Yield Estimates by Geographic Region

III. Farmers Home Administration

- A. Association Loans for Irrigation & Drainage, and Other Soil and Water Conservation Measures
- B. Resource Conservation and Development (RC&D) Loans
- C. Watershed Loans
- D. Soil and Water Loans to Individuals

IV. Forest Service

- A. State and Private Forestry
- B. Research
- C. National Forestry System

V. Science and Education Administration/Cooperative Research (formerly Cooperative State Research Service)

- A. Conservation Research in Agriculture and Forestry

VI. Science and Education Administration/Extension (formerly Extension Service)

- A. Land and Water Conservation Education

VII. Science and Education Administration/Agricultural Research (formerly Agricultural Research Service)

- A. Soil, Water, and Air Sciences Research

VIII. Soil Conservation Service

- A. Conservation Operations Program
- B. Cooperative River Basin Studies
- C. Watershed Planning (PL-566)
- D. Watershed Operations (PL-566)
- E. Flood Prevention Operations (PL-534)
- F. Emergency Watershed Operations (Section 216)
- G. Resource Conservation and Development Program (RC&D)
- H. Great Plains Conservation Program
- I. Inventory and Monitoring Program
- J. Flood Plain Management Assistance Program
- K. Soil Survey Program
- L. Snow Surveys and Water Supply Forecasting
- M. Plant Materials Center Operation

Table 3. LAND AND WATER CONSERVATION FUNCTIONAL OBJECTIVES AND SUBOBJECTIVES

I. Flood Control

- A. Sedimentation
- B. Erosion, floodwater
- C. Surface water supply
- D. Surface drainage (upland runoff)

II. Water Supply

- A. Water quality (pollution)
- B. Soil moisture
- C. Surface water supply
- D. Ground water supply

III. Watersheds

- A. Water quality (pollution)
- B. Sedimentation
- C. Channel stability
- D. Erosion, general (construction, timber harvest)
- E. Erosion, gully
- F. Erosion, sheet

IV. Wind Erosion

- A. Vegetative biomass
- B. Erosion, wind

V. Land Reclamation

- A. Soil salinity
- B. Erosion, general (mining)
- C. Vegetative biomass
- D. Economic product - yield
- E. Soil fertility
- F. Soil moisture
- G. Tilth & structure

VI. Irrigation (Water Management)

- A. Water quality (return flows)
- B. Soil salinity
- C. Water distribution efficiency
- D. Water use efficiency
- E. Subsurface drainage

VII. Drainage

- A. Water quality (pollution)
- B. Surface drainage
- C. Subsurface drainage

VIII. Cropland

- A. Vegetative biomass
- B. Economic product - crop yield
- C. Losses due to damage or harvest
- D. Soil fertility
- E. Soil moisture
- F. Tilth & structure

IX. Pasture/Range

- A. Vegetative biomass
- B. Economic product - yield (improve vegetation)
- C. Losses (reduce damage by livestock)
- D. Soil fertility
- E. Soil moisture
- F. Tilth & structure

X. Timber

- A. Vegetative biomass
- B. Economic product - timber yield (productivity)
- C. Losses (reduce timber losses)
- D. Soil fertility
- E. Soil moisture
- F. Tilth & structure

XI. Waste Management

- A. Water quality (pollution)
- B. Vegetative biomass
- C. Soil fertility
- D. Soil moisture
- E. Erosion, sheet

XII. Fish Habitat

- A. Water quality
- B. Vegetative biomass
- C. Surface water supply
- D. Species populations

XIII. Wetland Wildlife Habitat

- A. Water quality
- B. Soil salinity
- C. Sedimentation
- D. Erosion, general
- E. Vegetative biomass
- F. Species populations

XIV. Upland Wildlife Habitat

- A. Vegetative biomass
- B. Species populations

XV. Water-Based Recreation

- A. Water quality
- B. Land quantity
- C. Surface water supply
- D. Species populations

XVI. Land-Based Recreation

- A. Land quantity
- B. Species populations

Table 4. LAND AND WATER CONSERVATION PRACTICES AND MEASURES

I. Structural

1. Dam, Multiple-Purpose
2. Debris Basin
3. Diversion
4. Pond
5. Irrigation Field Ditch
6. Firebreak
7. Floodwater Retarding Structure
8. Grade Stabilization Structure
9. Grassed Waterway or Outlet
10. Irrigation System
11. Irrigation System Tailwater Recovery
12. Irrigation Land Leveling
13. Access Road
14. Spring Development
15. Open Channel
16. Terrace
17. Subsurface Drainage
18. Surface Drainage
19. Irrigation Canal or Lateral

II. Non-Structural

1. Waste Management System
2. Brush Management
3. Woodland Improved Harvesting
4. Chiseling and Subsoiling
5. Conservation Cropping System
6. Conservation Tillage
7. Contour Farming
8. Prescribed Burning
9. Cover and Green Manure
10. Critical Area Planting
11. Crop Residue Management
12. Field Windbreak
13. Fishpond Management
16. Pasture and Hayland Management
17. Proper Grazing Management
18. Range Seeding
19. Reclamation of Surface Mined Land
20. Recreation Area Improvement
21. Stream Channel Stabilization
22. Stripcropping
23. Tree Planting
24. Waste Utilization
25. Wildlife Wetland Habitat Management
26. Wildlife Upland Habitat Management

Table 5. LAND AND WATER CONSERVATION SUBOBJECTIVES AND PERFORMANCE INDICATORS

I. Water Quality

A. PH
B. Nitrate, carbonates, phosphates, etc. (salts)
C. COD (chemical oxygen demand)
D. BOD (biological oxygen demand)
E. Sediment (ppm)
F. Coliform count
G. Dissolved oxygen
H. Water temperature
I. Pesticide levels

II. Soil Salinity

A. Salt levels accumulation
B. Acres

III. Sedimentation

A. Ppm in stream
B. Ac. ft. deposited per ac. ft. of flow
C. Tons of soil delivered to a particular site

IV. Erosion

A. Tons soil/acre
B. Tons soil/ac. ft. flow
C. Tons of soil/ac./yr.
D. No. of acres, gullies, etc.
E. Nutrients eroded (lb./ac.)
F. Pesticides eroded (lb./ac.)

V. Vegetative Biomass

A. AUM's (Animal Unit Months)
B. Total digestible protein
C. Total digestible nutrients
D. Total dry matter
E. Percent organic matter
F. Volume and density:
   ground cover
   0 - 2 ft.
   2 - 10 ft.
   over 10 ft.
   canopy
G. No. acres

VI. Channel Stability

A. Aggradation
B. Degradation
C. Bedload movement
D. Sediment yield

VII. Economic Product - Yield

A. Yield: crops - bushels, bales, etc. per acre
   timber - bd. ft. per acre
   range - lb. or ton per acre or AUM's
B. Change in yield
C. Percentage change in yield
D. No. acres
E. Yield quality

VIII. Losses - Due to Disease, Pests, Fire, Harvest, Natural Disaster, Etc.

A. Loss: crops - bushels, bales, etc. per acre
   timber - bd. ft. per acre
   range - lb. or ton per acre or AUM's
B. No. acres lost or damaged
C. Percent of acres, stand, etc. lost
D. Amount usable, but not harvested
E. Percentage of amount usable which was not harvested

IX. Soil Fertility

A. Change in crop yield
B. Percentage change in yield
C. Change in ambient soil fertility
D. PH
E. N, P, K levels (lbs./acre)
F. Micronutrients
G. Percent of organic matter

X. Soil Moisture

A. Atmosphere tension of soil
B. Moisture holding capacity/in. top soil
C. No. acres
D. Rooting depth

XI. Tilth & Structure

A. No. acres
B. Percent of organic matter
C. Percent of silt, clay, and loam
D. Aeration

XII. Water Distribution Efficiency

A. Water delivered to farm vs. amount delivered to a field

XIII. Water Use Efficiency

A. Water use per unit yield

XIV. Land Quantity

A. No. of acres, miles of shoreline, etc.
B. Percent of total acres

XV. Surface Water Supply

A. Cfs in stream or ac./ft.
B. Ac. ft. of stored water available
C. Storage capacity
D. Depth (ft. or meters)
E. Ac. ft. on surface
F. Acres covered (flooded

XVI. Subsurface Water Supply

A. Feet below surface water level
B. Ft. of water in acquifer
C. Infiltration rate into acquifer (cfs)

XVII. Surface Drainage

A. Change quantity in cfs at specified place

XVIII. Subsurface Drainage

A. Cfs from drain outlets
B. Atmosphere tension of water in soil

XIX. Species Population

A. Population/acre (wildlife) or population/ac. ft. (fish)
B. Population as percent of desirable capacity

Table 6. LAND AND WATER CONSERVATION INDIRECT IMPACTS (Examples)

I. Environmental Quality

   A. Land
   B. Water
   C. Air
   D. Fish and wildlife

II. Economy

   A. Employment
   B. Prices
   C. Exports
   D. Agriculture and forestry earnings
   E. Capital inputs into agriculture and forestry
   F. Capital accumulation and concentration
   G. Future amounts of flows and stock resources
   H. Other industries
   I. Regional and local development

III. Energy

IV. Land Use

Program activities also cause indirect impacts, some of which are unplanned. For example, conservation programs can influence land and energy use, water quality, and fish and wildlife habitat. Education and analytic systems should be designed to account for indirect impacts (see Table 6 for examples).

Scope of LAWREMS

LAWREMS should contain data files and models to serve multiple purposes. One criticism of previous evaluation work has been that duplicate data files and models have been developed to study somewhat parallel program evaluation activities. LAWREMS should be designed to minimize overlap of data files and models. At the same time, data gathering and model building activities should incorporate as many analytic needs as practical.

The core of information in the LAWREMS system consists of models and data within USDA agencies (ASCS, ESCS, FmHA, FS, SEA, SCS). Some directory entries describe relevant data and models outside USDA (USGS, BLM, EPA, DOE, and others). Although it is unlikely that USDA analysts will be able to use these models and data at present, the knowledge that they exist may prove quite useful. When a USDA user specifies a need for data located in, for instance EPA, it would cost less in general, to obtain the data from EPA than to collect, edit and verify the raw data.

Currently, LAWREMS support services provide information, limited access to data and models within USDA, and some technical assistance to USDA land and water conservation program evaluators and impact analysts. The Directory would be available to other USDA personnel upon request, but technical assistance would be negligible at present. However, provision of this type of assistance in the future to other USDA researchers would maximize LAWREMS' service potential.

In summary, the LAWREMS concept is one of providing assistance to policy and program planners and evaluators through systematic data collection and the use of systems analysis. LAWREMS should perform a communication function by providing information on existing files and systems as well as needed capability for use in evaluation. LAWREMS should encourage the upkeep, maintenance, and use of existing files and models pertinent to land and water conservation program evaluation. LAWREMS should be in a position to provide direct access to certain files and models to agency users. LAWREMS staff should help train agency personnel in the use of models. LAWREMS should be sufficiently comprehensive to include systems for all of the conservation programs and functional objectives of the Department. The files and models in LAWREMS should be designed for multiple-purpose use to minimize duplication and to encourage broader application of systems available and under development.

The LAWREMS information base and conceptual framework is never complete. LAWREMS should change, adapt and be refined as program missions and evaluation criteria change, and as new models are developed and data sets created.

LAWREMS INFORMATION SYSTEM

An information system, as its name suggests, contains information concerning data sets and models, it does not contain the data or models themselves. Currently, the LAWREMS Information System has direct access to a limited number of data and models, however. The LAWREMS Directory is automated on computer, as are two other well-known information systems, CRIS (Current Research Information System) and NAL (National Agricultural Library). Others may be published as directories or bibliographies, rather than being automated.

The LAWREMS information system is a type of "information desk" designed to address the subject of USDA land and water conservation programs. The Phase I LAWREMS "information desk" had four components:

(1) A Directory of data and model systems;

(2) A file of related documentation and reports;

(3) A mini-computer to facilitate access and transferral of data and models;

(4) A staff to provide maintenance of the Directory and technical assistance to users.

LAWREMS Directory

The Directory currently comprises about 300 systems in three sections: 1) Data Sets (125); 2) Programs and Models (160); and, 3) Information Systems (15). Directory entries contain information received in response to questionnaires developed by the LAWREMS staff. Requested information included title, agency, abstract, purpose, keywords, geographic coverage, operational status, availability, name of technical contact, special requirements, and various technical information. In many cases, documentation was provided to supplement the information.

Descriptions were provided voluntarily by government agencies, universities, companies, and individuals, and were recorded, in most cases, in the form received with only minor additions, deletions, and editorial changes.

In addition, information was obtained from the following sources:

1. ESCS Database Information,
   ESCS/Data Management and Support.

2. Computer Applications Inventory,
   U.S. Forest Service.

3. Resource and Management Information System (RAMIS), Soil Conservation Service.

4. File of Agricultural Research Models (FARM), SEA/Agricultural Research (formerly ARS).

5. Federal Data Exchange (DATEX), Bureau of Land Management.

At the present time, selections have not been made from information systems such as the Current Research Information System (CRIS) and the National Agricultural Library (NAL). Data and models pertaining to land and water conservation in these systems must be searched separately. As experience is gained in using these systems, the relevant files and models may be referenced directly in the LAWREMS system. In the meantime, the Information Systems section of the LAWREMS Directory lists NAL, CRIS, and other bibliographies and directories to provide the user with further sources of reference.

Current Capabilities

The Directory is designed to provide easy identification of relevant data sets and models through the keyword index. Words included in the index are both user-supplied and assigned by the Directory staff. The latter are for use in USDA program evaluation and place special emphasis on conservation program objectives, subobjectives, structural and nonstructural practices, and performance indicators (see Tables 3, 4, and 5). Examples of the types of information and related keywords:

1. Policy Issues and Problems To Be Addressed:

   Keyword examples: Water quality; water supply; alternative techniques; costs and benefits; performance indicators; resource scarcities; environmental impacts; land use; planning; management; administrative efficiency; development; budget; income; employment; policy.

2. Program Objectives:

   Keyword examples: Watershed; flood control; recreation; timber; productivity; crop yield; soil loss; erosion; sedimentation; water quality; irrigation; rural development; improvement; management.

3. Program Practices:

   Keyword examples: Irrigation; drainage; wind break; management; construction; terrace; tillage; infiltration; soil movement; pesticides; distribution of funds; flow of funds; budget.

4. Impacts:

   Keyword examples: Water supply; water quality; crop productivity; soil fertility; yield; costs; benefits; food and fiber system; economic impacts; environmental impacts; survey; inventory; impact analysis; wildlife; community impacts; prices.

5. Methodology:

   Keyword examples: Linear programming; optimization; cost/benefit analysis; alternative futures; simulation; evaluation; input-output; estimation; forecasting; simultaneous equations.

When areas of interest have been identified by use of keywords in the index, the user observes the serial number to determine which items appear most relevant to his needs, then uses the number to locate the item's description in the Directory (see appendix for examples of Directory entries). From the Directory narrative:

(1) The user can form an opinion as to the quantity, quality, complexity, and usefulness of a given data set or model. Commmon elements can be identified which permit the linking of data sets.

(2) The user can determine the location, availability, and/or ease of moving a data set or model. When systems are available from several sources, the user can choose that which is most compatible with his needs.

(3) Data and models not available can be pinpointed, indicating possible gaps in research.

(4) Linkages among models and data can be identified to a degree.

The LAWREMS Directory thus allows the analyst to cross-reference the characteristics of his evaluation problem with the features of the available models and data sets. All descriptions include the name and address of a person familiar with the details of the model or data set, allowing the analyst to identify and consult with those responsible for the system. This consultation can be aided and supplemented by interfacing with the LAWREMS staff.

The staff could also provide some technical assistance, as it is familiar with and experienced in using many of the data and model systems. Also, the LAWREMS backup files of systems documentation and related reports can be used to provide information in addition to that found in the Directory.

Three attempts to increase the usefulness of the keyword index are proposed: First, a cross-reference subroutine is under development. Cross-referencing is needed to locate useful information while avoiding that which is not pertinent. Many descriptions provide only general information on content, e.g., watersheds and wind erosion. If the user is interested only in wind erosion in a watershed, the cross-reference subroutine will compare the

serial numbers given for these keywords and print those numbers which include both. In this way, the user can avoid locating an item on drainage in watersheds which has nothing to do with wind erosion.

Second, an accepted keyword list could be formulated for use by contributors when completing questionnaires. This would considerably enhance the consistency of keywords. In particular, it is important to standardize the terminology and measurement units of performance indicators.

Third, it is possible to develop a version of the Directory which would list subsets rather than the complete volume. This option would be useful when a person has selected only a small number of descriptions for review.

Access to Directory.--The Directory was assembled to support land and water conservation policy, program planning and evaluation, and impact analyses. The principal access, therefore, is intended for persons in these areas. Making the compiled information available to technical personnel working on data and models is a desirable extension of the system, perhaps in Phase II. With the improved flow of information, redundancies may be reduced, and more rapid development of policy tools is ensured. The LAWREMS team feels that subsets of the Directory should be made available to any interested party, government or private, including university researchers.

A few cases exist where data files contain sensitive information and are accessible only to certain personnel in a given agency. The question arose whether descriptions of these files should be included in the Directory. Their inclusion could assist persons engaged in program evaluation, while their omission would render the Directory incomplete. The LAWREMS Team agreed that such data set descriptions would be included, if the agency controlling them so desired, but would be flagged under a security code.

As of September 1978 the Directory, backup files, and mini-computer are housed with the Resource Systems Program of the Natural Resource Economics Division of the Economics, Statistics, and Cooperatives Service (ESCS). This group provided the principal staff for the first phase of LAWREMS. The future home, if any, will be decided by USDA officials under advisement from the Land and Water Conservation Task Force.

Selection and Revision Criteria

Policy questions posed are generally very broad, reflecting the multiple objectives of agency programs. To answer such policy questions about conservation programs requires an interdisciplinary approach. However, few models designed for policy planning and program evaluation are in existence or under development. In large part, existing data sets and models are much more basic, being designed for investigation of a single or narrowly defined issue in sufficient depth to advance the current state of knowledge on the subject. Such models are not, therefore, directly applicable to program evaluation, but should be included in the Directory as relevant information because of their potential when linked to other models. In practice such linkage may be difficult to achieve for

a variety of reasons, including, but not limited to:

(1) Inconsistencies in data which prevent aggregation.

(2) Inconsistencies in models and/or methodologies, such that output of one model may not be appropriate as input for another.

(3) Lack of information or research on some of the system's components. Policy questions often are posed in areas where little research has yet been accomplished.

(4) Lack of information or research on the interactions and linkages between the components which make up the system.

This suggests a need for a link between agency research activities and policy and program analysis. LAWREMS can provide this link.

The criteria for inclusion of a system in the Directory can be stated in the form of three questions:

"Does it provide a quantitative value (physical or economic) for any of the items listed as objectives, subobjectives, practices, and/or performance indicators in Tables 3, 4, and 5?"

"Is it designed for the purpose of program evaluation, policy analysis, impact analysis, management, or planning?"

"If the model was developed to describe a situation, does it have evaluation or linkage potential?"

If an answer was yes to any question, the model or data set was included.

The Directory will be updated continuously as systems descriptions arrive at the LAWREMS office. Current plans are to send an update form to those developers whose items were selected from other directories. This is to insure that the current version of these entries is contained in the LAWREMS Directory. In addition, an update will be requested for all systems at regular intervals.

Due to the large quantity and variety of computerized systems in USDA and the limited time schedule for completion of the inventory, it was not always possible to contact a developer directly when questions arose concerning the use of a particular model or data set. Therefore, a few systems included in the Directory may be considered marginal. The decision to include more instead of fewer in the initial Directory was made for two reasons. First, linkages have not been fully identified; consequently, a system that appears marginal may not be. Second, inclusion of such systems allows continuing contact with an analyst or researcher who is working in the field. Since most systems are active, change will be continual. Some possible criteria for Directory revisions to improve the system are:

1. Non-relevance.--Many contributors related their data and models to program objectives and subobjectives; fewer associated their systems with practices; and a very small percentage of the descriptions detailed output or data in terms of performance indicator units. The LAWREMS staff could combine the elements of Tables 3, 4, and 5 into a checklist to be sent to system developers. The developers could then check those objectives and practices to which their systems apply. They could also check those performance indicators which are included in their data set's or model's output. Any system revealed as unrelated to objectives, programs, practices, or performance indicators would be eliminated from the Directory.

2. Standardization.--At present there may be more than one included system dealing with the same issue because: 1) models may differ in methodology; 2) data may differ in units of measure, geographic division and coverage, or time span; 3) two data sets or models may be virtually the same, but located in different agencies. Inclusion of apparent "redundancies" allows the user to choose that system which best fits his needs or which is most accessible because it may be within his own agency. If and when standardization occurs in units of measure or methodology, some systems can be removed from the LAWREMS Directory.

3. Gaps.--As noted previously, many systems that were included in the Directory are singular in purpose. As models are developed to link micro models, it may be possible to eliminate some systems from LAWREMS. As researchers use the Directory over time, gaps will be recognized. Systems developed to fill these gaps may replace some existing LAWREMS models.

A user's procedure for selecting appropriate analytical systems can never be fully automated since it is not possible to incorporate all relevant characteristics of every problem. The Directory can be used only as a guide. Thus, the evaluators and analysts who work with the LAWREMS staff must utilize their own criteria for selecting appropriate systems.

Access to Models and Data

One of the charges given the LAWREMS team was to improve USDA and Congressional access to available models. Improved access has two aspects. First, models and data must be identified as to their physical location, available documentation, and applicability to the problem. Second, the time required to gather the needed input data, run the model, and produce a meaningful report is very important in determining the usefulness and accessibility of a model. If the needed report cannot be produced in the time frame necessary, the model is not helpful. At present the Directory emphasizes the first aspect. The Directory also shortens the time lag in

locating pertinent data and analytic systems. However, much more needs to be done to expedite the sequential process and smooth the flow of providing model results to policymakers.

Technical assistance.--Once useful information has been identified which is compatible with the skills, needs, and equipment of the user, several options are available. If LAWREMS is continued, the LAWREMS office and staff could be used as an information desk to provide backup materials and support to the user. In addition, the LAWREMS staff could provide "hands on" training to some users on selected data and analytic systems. Alternatively, the user may choose to contact the technical information person directly to request assistance, advice, and bibliographic material. For many applications the user may find it expedient to make arrangements with the technical contact to print the data or run the model in the form desired.

The Directory entries include two categories concerning restrictions on availability. One is whether the data includes information which falls under the Privacy Act; the other is whether the data is classified, for in-house use only, or available. If the data is restricted in any of the above ways, it may be possible for the user, if outside the controlling agency, to reimburse the agency for processing the data into a form in which it can be released. The final decisions on such agreements and data releases where sensitive information may be involved should be the sole responsibility of the controlling agency.

Terminal access.--In many cases sufficient documentation is available in the form of user's manuals to allow remote access through a standard phone terminal. Such terminals are readily available to most users, and most computer centers have phone connection facilities. A potential user should realize it is not necessary for a model or data set to be available in an "interactive mode" in order to use a remote terminal. A large portion of the models and data listed in the Directory are designed for "batch" operation. Batch means a job is submitted to the computer and output is picked up at a later time. This type of processing is desirable when (1) data tapes must be mounted, (2) the cost of processing encourages the use of cheaper night rates, (3) processing is very slow because a large portion of the computer is needed to run the model, or (4) large amounts of output are produced. Most major computer centers have sufficient flexibility to allow batch jobs to be submitted from phone terminals. Results from the job can be stored on print files retrievable from the computer at a later time using the same remote terminal. If large amounts of output are produced, results can be printed on a high speed printer and picked up or mailed to the user. Again, most computer centers have mail bins where output can be dumped for mailing.

A second alternative to accessing computers is through the use of an "intelligent terminal." The LAWREMS staff is currently testing this form of access. An intelligent terminal is a mini-computer with its own storage, editing, and language capabilities. Such a system has several potential advantages. It may be necessary to move data from one computer system to another. The normal procedure is to mail tapes or cards between centers. All too often the tapes are not readable in the form in which they are

received because the computers are not compatible. Cards, on the other hand, are very restrictive, bulky, and expensive. The intelligent terminal can be used to move moderate amounts of data between centers. This type of terminal has the capability to act as an "interpreter" for the two computers since it converts everything to a standard code. As a result, data can be transmitted in minutes rather than days, and the technique of using output from one model at one location as input into a second model at a second location becomes feasible.

A second advantage of an intelligent terminal is that it can be programmed. Reports, summary tables, and graphs can be produced using the computer capabilities of the terminal. One may wish to run several alternative models at multiple locations. Model output can be consolidated, additional statistical tests can be calculated, and the combined analysis can be presented in a single summary report.

A third advantage is in the mini-computer's ability to store information. Many of the models and data sets are accessible by anyone with a user's manual and a valid computer account, but certain "learning time" is still required before a program can be successfully operated. The storage facilities of the mini-computer can be used to store instructions to the user and error-free command files, which are sent to the large computer automatically when phone contact is achieved. Instructions and command files are stored on small disks or tape cassettes, which can be filed along with the other backup documentation. When needed, these files are simply loaded into the intelligent terminal. The use of mini-computers for this purpose is new and not fully explored. A test in the fall of 1978 will provide additional information on the gains in efficiency resulting from this technology.

RCA: Using the LAWREMS Capabilities

A critical test of the LAWREMS system capabilities will occur in the winter of 1978-79 when Phase I staff provide analytical support for the Resources Conservation Act 1980 Report.

For the most part, analyses for the 1980 Report will necessarily be done using existing operational and accessible models and data. Time will permit only slight modifications. The LAWREMS Directory and documentation will be an aid to identifying appropriate data, models, and methodology for the analyses to be undertaken.

Concurrently, and resulting from this process, data and model gaps will be identified. Many of the recognized gaps will be filled prior to conducting the analyses for the RCA 1985 Report. During the next five years, a more comprehensive analytic model can be designed, and the needed data can be collected.

With "hands on" experience in using some of the models and data, the LAWREMS staff should facilitate the analysis and reporting process. The complexity of the RCA task, the extremely short time period available for the analysis, and the unprecedented nature of the effort combine to create an environment for rigorous testing of the many facets of the LAWREMS service.

A Field-Scale Model for Nonpoint Source Pollution Evaluation[1/]

W. G. Knisel[2/]

Mathematical models to assess nonpoint source pollution and evaluate the effects of management practices are needed to adequately respond to the Water Quality Legislation of the past 10 years. Action agencies must assess nonpoint source pollution from agricultural areas, identify problem areas, and develop conservation practices to reduce or minimize sediment and chemical losses from fields where potential problems exist. Monitoring every field or farm to measure pollutant movement is impossible, but farmers need to know the benefits before they apply conservation practices. Only through the use of models can pollutant movement be assessed and conservation practices planned.

Models developed for these purposes include the Pesticide Runoff Transport (PRT) model to estimate runoff, erosion, and pesticide losses from field areas (Crawford and Donigian, 1973); the Agricultural Runoff Model (ARM) to estimate runoff, erosion, and pesticide and plant nutrient losses from field areas (Donigian and Crawford, 1976); and the Agricultural Chemical Transport Model (ACTMO) to estimate losses from field or basin size areas (Frere, Onstad and Holtan, 1975). Bruce, et al. (1975) developed an event model to estimate pesticide losses from fields during single runoff-producing storms. These models are expensive when several years of data are simulated, and all require calibration. Beasley, et al. (1977) developed the ANSWERS model to estimate runoff and erosion and sedimentation from basin sized areas. This model has been used to identify sources of erosion and to consider conservation practices for erosion control, but it does not estimate nutrient or pesticide movement.

In 1978, the U.S. Department of Agriculture, Science and Education Administration, Agricultural Research (USDA-SEA-AR), began a national project to develop relatively simple and inexpensive mathematical models for evaluating nonpoint source pollution. A model that does not require calibration was planned, since very little calibration data are available. The initial efforts were concentrated on field scale, since that is where conservation management systems are applied. A field was defined as an area with relatively homogeneous soils under a single management practice that was small enough that rainfall variability was minimal. Requirements for the model were that it be simple and yet represent a complex system, be physically based and not require calibration, be a continuous simulation model, and have the potential to estimate runoff, erosion, and adsorbed and dissolved chemical transport. A field-scale model has been developed and is operational.

[1/] Contribution from the U.S. Department of Agriculture, Science and Education Administration, Agricultural Research.

[2/] The author is a hydraulic engineer, USDA-SEA-AR, Southwest Rangeland Watershed Research Center, Tucson, Arizona. This paper represents contributions from seven lead scientists and 40 contributing scientists in SEA-AR.

The purpose of this paper is to present the concepts and describe application of the field scale model. Details of the model cannot be given because spaces limited, but each component is described. A manuscript in the process of publication will describe the model in detail and give instructions for its use[3/].

CREAMS MODEL STRUCTURE

The model reported in this paper consists of three major components: hydrology, erosion/sedimentation, and chemistry. The hydrology component estimates runoff volume and peak rates, evapotranspiration, soil water content, and percolation, all on a daily basis. The erosion component estimates erosion and sediment yield including particle size distribution at the edge of the field. The chemistry component includes a plant nutrient element and a pesticide element. Stormloads and average concentrations of adsorbed and dissolved chemicals are estimated in the runoff, sediment, and percolation fractions.

The Hydrology Component

This component consists of two options, depending upon availability of rainfall data. If the user is limited to daily rainfall data, Option 1 provides a means of estimating storm runoff. If hourly or breakpoint (time-intensity) rainfall data are available, Option 2 offers the user an infiltration-based method of estimating storm runoff.

Option 1: Williams and La Seur (1976) adapted the Soil Conservation Service (1972) curve number method for simulation of daily runoff. The method relates direct runoff to daily rainfall as a function of curve number (Fig. 1). Curve number is a function of soil type, cover, management practice, and antecedent rainfall. The relationship of runoff, Q, to rainfall, P, is

$$Q = \frac{(P\ 0.2S)^2}{P + 0.8S} \tag{1}$$

where S is a retention parameter related to soil moisture. A water balance is calculated by

$$SM_t = SM + P - Q - ET - O \tag{2}$$

where SM is initial soil moisture, SM_t is soil moisture at day t, P is precipitation, Q is runoff, ET is evapotranspiration, and O is percolation below the root zone. Eq.(2) estimates the soil water for determining the retention parameter, S, in Eq. (1).

The percolation component uses a storage routing technique to estimate flow through the root zone. The root zone is divided into 7 layers -- the first layer is 1/36 of the total root zone depth, the second layer 5/36 of the total, and the remaining layers, all equal in thickness, are 1/6 of the root zone depth. The top layer is approximately equivalent to the chemically active surface layer and the layer where interrill erosion is active. The soil water capacity for each layer is defined as the field

[3/] U.S. Dept. of Agri., Science and Education Administration. CREAMS: a field scale model for estimating Chemicals, Runoff, and Erosion from Agricultural Management Systems. To be published as a USDA-SEA Conservation Research Report.

capacity, and percolation cannot occur until the field capacity is exceeded. Percolation through a layer is based on the saturated hydraulic conductivity.

The peak rate of runoff, q_p, (required in the erosion component) is estimated by the empirical relationship

$$q_p = 200D^{(0.7 + 0.23e^{-4.7D})}\ C^{0.159} Q^{(0.917D^{0.0166})} L^{-0.187} \qquad (3)$$

where D is drainage area, C is mainstem channel slope, Q is daily runoff volume, L is the watershed length-width ratio, and e is the base of natural logarithms. Although Eq. (3) was developed and tested for basin-sized areas, it has been found applicable to field-sized areas as well.

<u>Option 2</u>: The infiltration model is based on the Green and Ampt (1911) equation (Smith and Parlange, 1978). A defining diagram of the infiltration model is given in Fig. 2. The concept assumes that the soil contains some water initially in a surface infiltration-control layer at the time rainfall occurs. When rainfall begins, the soil water content in the control layer approaches saturation and surface ponding occurs at some time, t_p (Fig. 2). The amount of rain that has already infiltrated at time of ponding, designated F_p in Fig. 2, is analogous to the initial abstraction in the SCS curve number model (Option 1), but it is a function of rainfall rate in this option. After the time of ponding, the Green and Ampt (1911) equation assumes that water moves as a sharply defined wetting front with a characteristic capillary suction, H_c, as the principle driving force. At any time, the potential gradient is

$$g = \frac{H_c + L}{L} \qquad (4)$$

where L is the depth of wetting. The flow, f, is the product of effective conductivity, K_s, and the gradient, or

$$f = K_s \frac{H_c + L}{L}. \qquad (5)$$

The infiltrated depth, F, (Fig. 2) is

$$F = L(\Theta_s - \Theta_i) \qquad (6)$$

where Θ_s is the water content at saturation and Θ_i is the initial water content. The infiltration capacity, f_c, becomes

$$f_c = K_s \frac{(H_c \Theta_s - \Theta_i) + F}{F} \qquad (7)$$

where Θ_s approaches the soil porosity, ϕ, and, letting $G = \phi H_c$ the infiltrated depth at t_p is

$$F_p = \frac{G(S_s - S_i)\ K_s}{r - K_s} \qquad (8)$$

where r is rainfall rate. If $D = (S_s - S_i)$, and approximating the infiltration curve of Fig. 2 by a series expression for the natural logarithm, the infiltrated depth in a time interval, ΔF, is

$$F = \quad 4A(GD + F) + (F - A)^2 + A - F, \qquad (9)$$

where $A = \frac{K_{si} \Delta t}{2}$. The average infiltration rate for any interval i, f_i, is

$$\bar{f}_i = \frac{\Delta F_i}{\Delta t_i} \tag{10}$$

and runoff during the interval, q_i, is rainfall rate for the interval minus the infiltration rate, $r_i - \bar{f}_i$. Total runoff is the sum of all q_i for the storm. Thus, the infiltration-based model has three parameters: G, D, and K_s.

The percolation estimated is similar to that used in Option 1, except that a single layer below the infiltration control layer represents the root zone. Percolation is calculated using average profile soil water content above field capacity and the saturated hydraulic conductivity, K_s.

Peak rate of runoff is estimated in Option 2 by attenuating the rainfall excess using the kinematic wave model for flow over a simple plane (Wu, 1978). The plane is approximated by the field slope and flow length.

Evapotranspiration: The evapotranspsiration (ET) element of the hydrology component is the same for both options. The ET model, developed by Ritchie (1972), calculates soil evaporation and plant evaporation separately. Evaporation is based on heat flux and is a function of daily net solar radiation and mean daily temperature. It is calculated in two stages: the first is potential soil evaporation to modify the moisture flux based upon plant canopy or leaf area index, and the second stage is a function of time and an evaporation constant. Plant evaporation is computed as a function of soil evaporative flux and leaf area index. If soil water is limiting, plant evaporation is reduced by a fraction of the available soil water. Evapotranspiration is the sum of plant and soil evaporation but cannot exceed potential soil evaporation.

Erosion

The erosion component of the CREAMS model considers the basic processes of soil detachment, transport, and deposition. The concepts of the model are that sediment load is controlled by either transport capacity or the amount of sediment available for transport, whichever is less. If sediment load is less than transport capacity, detachment may occur; deposition occurs if sediment load is greater than transport capacity. The model represents a field comprehensively by considering complex slopes for overland flow, concentrated channel flow, and impoundments or ponds. The model can estimate particle size transport for the primary particles -- sand, silt, and clay -- and large and small aggregates. Detachment and deposition do not occur simultaneously. In deposition, the model calculates sediment sorting. Temporary ponding can result in transport of only the finer particles.

The detachment process is described by a modification of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) for a single storm event. This interrill detachment, D_{IR}, in the overland flow element is expressed as

$$D_{IR} = 4.57EI\ (S + 0.014)\ KCP/(q_p/Q), \tag{11}$$

where EI is storm rainfall energy, S is the slope of the overland flow, q_p is runoff peak rate, Q is runoff volume, K is the soil erodibility factor, C is the cover factor, and P is the management practice factor. The rill detachment process, D_R is expressed as

$$D_R = (6.84 \times 10^6)\, n_x Q q_p^{1/3} (x/22.1)^{n_x - 1} S^2 KCP(q_p/Q) \qquad (12)$$

where x is the distance down slope, n_x is slope-length exponent, and Q, q_p, K, C, and P are defined as above. As shown in Eq. (11), interrill erosion is a function of rainfall detachment and transport, and from Eq. (12) rill erosion is a function of transport capacity denoted by the runoff volume and peak rate. Both equations contain the K, C, and P factors of the USLE (Wischmeier and Smith, 1978). Sediment transport for the overland flow element is estimated by the Yalin transport equation (Yalin, 1963) modified for mixtures of sediment having varying sizes and densities.

The concentrated flow or channel element of the erosion model assumes that the peak rate of runoff is the characteristic discharge for the channel, and detachment or deposition is based on that discharge. Detachment can occur when the shear stress developed by the characteristic discharge is greater than the critical shear stress for the channel. Bare channels, grassed waterways, and combinations of bare and grass channels can be considered by the model for as many as 10 channel segments. Discharge is assumed to be steady state, but spatially varied, increasing downstream with lateral inflow. Friction slope and shear stress are estimated from solution of the spatially varied flow equations. The solutions consider drawdown or backwater effects in the channel as a result of channel outlet control.

Water is often impounded in field situations, either as normal ponding, where a channel flows through a restriction at a fence line or a road culvert, or as outflow from an impoundment-type terrace. Any such restriction reduces the flow velocity and coarse-grained sediments and aggregates can settle out of the flow. Deposition in impoundments is a function of the fall velocity of the particles and particle travel time through the impoundment. The fraction of particles passing through the impoundment, FP, of a given size, i, is given by the exponential relation

$$FP_i = A_i e^{B_i d_i} \qquad (13)$$

where d_i is the equivalent sand-grain diameter and A and B are coefficients.

In addition to calculating the sediment transport fraction for each of the five particle size classes, the model computes the sediment enrichment ratio, which is based on the specific surface area of the sediment and organic matter and the specific surface area for the residual soil. As sediment is deposited in transport, the organic matter, clay, and silt are the principle particles transported, and this results in high enrichment ratios. The enrichment ratios are important in adsorbed chemical transport.

Chemical Component

Plant Nutrients: The basic concepts of the nutrient component are that nitrogen and phosphorus are adsorbed to soil particles and are lost as sediment is transported, that soluble nitrogen and phosphorus are lost with surface runoff, and that soil nitrate can be leached by percolation, denitrified, or taken up by plants.

Nitrogen and phosphorus are mixed with the soil, and the amounts lost with sediment are a function of sediment yield and enrichment ratio. A logarithmic function is used to relate nitrogen and phosphorus losses to enrichment ratios.

The chemical model component assumes that an arbitrary surface layer 1 cm deep is effective in chemical transfer to sediment and runoff. Soluble nitrogen and phosphorus are assumed to be thoroughly mixed with the water in the top centimeter. This includes soluble forms from the soil, surface-applied fertilizers, and plant residues. These soluble nutrients are imperfectly extracted by overland flow. The extraction from this active layer is expressed by an empirical extraction coefficient. All broadcast fertilizer is added to the surface active layer, whereas only a fraction would be added by fertilizer incorporated with the soil.

When infiltrated rainfall saturates the surface active layer, soluble nitrogen moves into the root zone below the layer from which chemicals are extractable. Nitrate in the rainfall contributes to the total in both this layer and the root zone.

Fertilizer addition and mineralization of organic matter both increase soil nitrate. Mineralization is calculated by a first order rate equation from the amount of potential mineralizable nitrogen and is modified by soil water content and temperature. Optimum mineralization rates occur at soil temperatures of 35°C. Soil temperature is approximated by air temperature, as calculated in the hydrology component of the model.

The model assumes that plant uptake of nitrogen under ideal conditions is described by a normal probability distribution curve. The potential uptake is reduced to the actual by a ratio of actual ET to potential ET. A second option for estimating nitrogen uptake is based on plant growth and the plant's nitrogen content.

Soil nitrate is available to plants for uptake. It can also be leached out of the root zone, or denitrification can reduce it. The description of nitrate leaching in the model assumes uniform mixing of the draining water and the nitrate remaining in the soil. The amount of nitrate leached is a function of the amount of water percolated out of the root zone, as estimated by the hydrology component of the model.

Denitrification of soil nitrate in the root zone occurs when the soil water content exceeds field capacity, i.e., when percolation occurs. The amount of denitrification is based upon soil temperature and the organic carbon content of the soil. The model estimates organic carbon from the organic matter content in the root zone. The rate constant for denitrification at 35°C is calculated from the amount of organic carbon and is adjusted for temperature assuming a twofold reduction for each 10-degree decrease in temperature.

Thus, the plant nutrient component of the chemical model estimates nitrogen and phosphorus losses in sediment, soluble nitrogen and phosphorus in the runoff, mineralization, uptake by the crop, nitrate leached by percolate through the root zone, and denitrification in the root zone. The model computes loads of each component, accumulates over the year, and calculates average concentrations of nitrogen and phosphorus in runoff.

Pesticides: The pesticide model was developed to estimate concentrations of pesticides in runoff (water and sediment) and total mass for each storm during the period of interest. The model can accomodate up to 10 pesticides simultaneously in a single run. It is structured to consider foliar application of pesticides separately from soil-applied pesticides, because dissipation from foliage is more rapid than that from soil. The model can also consider multiple applications of the same chemical, as is done with insecticides.

As in the plant nutrient component, a surface active layer that is 1 cm deep is assumed. Movement of pesticides from the surface is a function of infiltrating water and pesticide mobility parameters. Pesticide in runoff is partitioned between the solution, or water, phase and the sediment phase by the following relationships:

$$(C_w Q) + (C_s S) = a C_p \qquad (14)$$

and

$$C_s = K_d C_w \qquad (15)$$

where C_w is pesticide concentration in water, Q is volume of water per unit volume of stirred runoff interface or surface active layer, C_s is pesticide concentration in sediment, S is the mass of soil per unit volume of interface, a is an extraction ratio of the amount of soil extracted per unit volume in the stirred runoff interface, C_p is the concentration of pesticide residue in the soil, and K_d is the coefficient for partitioning the pesticide between sediment and water phases. The concentration C_w is assumed to be the average concentration in solution that reaches the field edge but is determined by extraction of the pesticide into the runoff from the soil interface in the field. The term C_s is the pesticide concentration in the soil material at the runoff-soil interface after extraction. Only a small part of the this mass extraction actually reaches the edge of the field and is calculated as a product of concentration, sediment mass, and the enrichment ratio. The sediment mass and enrichment ratios are calculated by the erosion component of the model.

Pesticide washed off of foliage by rain changes the concentration in the soil. The amount calculated as available for washoff is updated between storms by a foliar degradation process. Pesticide residue in the runoff interface layer is adjusted for downward movement and washoff from foliage.

Summary

A physically based daily simulation model has been developed by SEA-AR scientists to evaluate nonpoint source pollution from agricultural fields. The model simulates processes in hydrology, erosion, and plant nutrient and pesticide losses as affected by management practices. It does not require calibration, and the computer program is computationally efficient -- it costs only a few dollars per year of computations.

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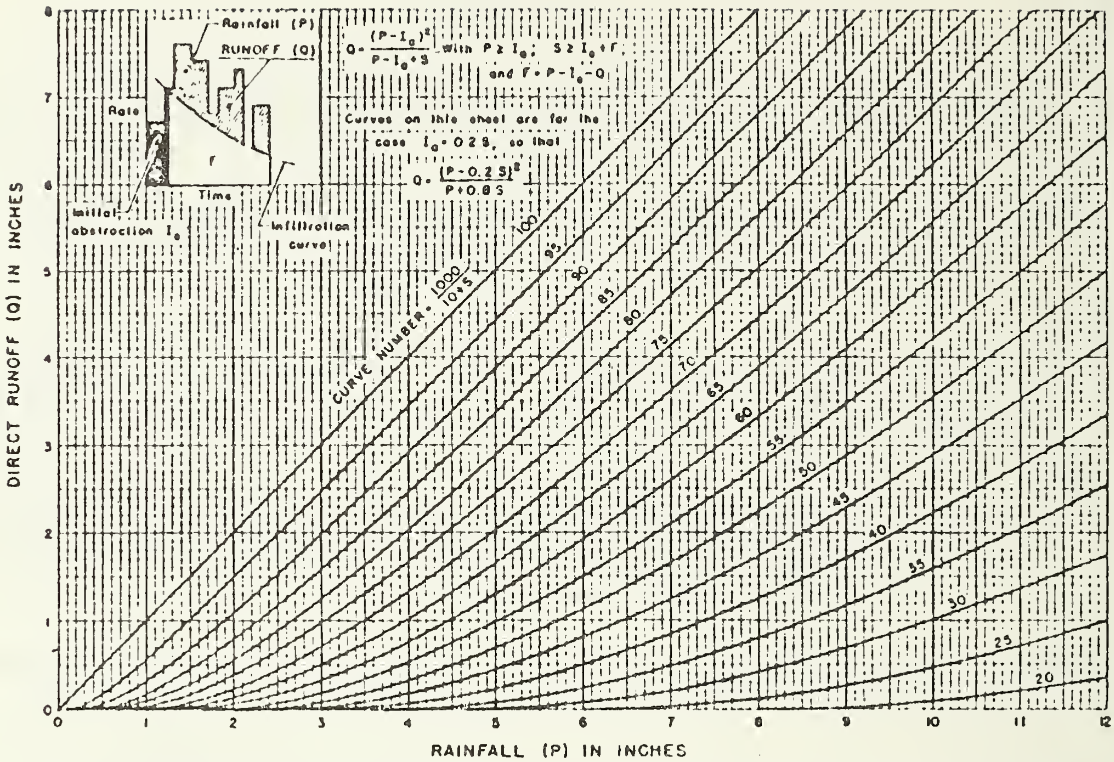

Figure 1. Soil Conservation Service curve number method of storm runoff estimation (USDA, Soil Conservation Service, 1972).

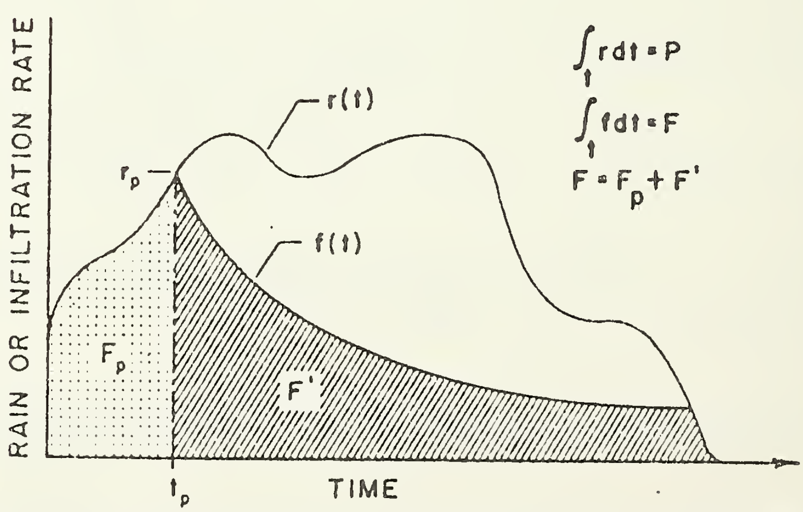

Figure 2. Schematic representation of runoff model using infiltration approach (Smith and Parlange, 1978).

MODELING OF WATERSHED RESPONSE FOR EVALUATING BEST MANAGEMENT PRACTICES AT COLORADO STATE UNIVERSITY

Daryl B. Simons, Associate Dean for Engineering Research and Professor of Civil Engineering.
Ruh-Ming Li, Associate Professor of Civil Engineering.
Colorado State University, Fort Collins, Colorado.

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INTRODUCTION

The increasing interest in water resource and land-use planning has stimulated the development of particular and general watershed and river system models for predicting response from ecological systems. The models, whether physical process simulation or conceptual, are intended to be used to estimate physical quantities that describe the major ecosystem responses to precipitation such as water yield, sediment yield, changes of land and river morphology, and transport of pollutants. Methods to estimate water, sediment, and other pollutant transport yields are needed for analyzing the economic feasibility and trade-offs of any proposed water resources or land-use development in watershed and river systems and for predicting possible adverse environmental impacts associated with the proposed land use practices or development. A practice or a combination of practices that yield a best management criterion considering the physical, social, economic, and legal constraints can be effectively determined by utilizing the modeling approach.

A mathematical model is simply a quantitative expression of a process or phenomenon that is being studied. In a conventional method of analysis, a series of manual calculations may be required. With the advancement of numerical techniques and computer technology, a series of tedious computations can be conducted efficiently, repeatedly, and adequately through the formulation and construction of a mathematical model. Utilizing a well developed model, a whole array of "what-if" questions can be answered with minimum requirement of time and effort. Since no process can be completely understood and observed, any mathematical expression of a process will involve some level of uncertainty. This uncertainty can be minimized if the governing physical processes are considered in the analysis and the model is properly designed, calibrated and verified. Model development, verification, and application to the real-world problems requires the consideration of the nature of the problems, physical environment, objective of the study, time, manpower, and money. Since time, manpower, and money always have limited resources, decisions must be made by the model users and developers as to the degree of complexity the model is to have, and the extensiveness of the verifications that are to be performed. According to Overton and Meadows (1976), if a highly complex mathematical representation of the system under study is made, the risk of not representing

the system will be minimized but the difficulty of obtaining a meaningful solution will be maximized. Much data will be required, programming effort and computer time will be large, and the general complexity of the mathematical handling may even render the problem formulation intractable. Further, the resource constraints of time, money, and manpower may be exceeded. Conversely, if a greatly simplified mathematical model without proper examination of physical significance is selected or developed, the risk of not representing the physical system will be maximized but the difficulty in obtaining a solution will be minimized. Figure 1 shows the general concept of "trade-offs" considering model complexity. The knowledge of governing physical processes and the sensitivity of system response plays the most important part in deciding on an appropriate level of analysis. It is possible to select or develop a model that is simple to use and involves a minimum level of risk if the governing physical processes are emphasized in the analysis.

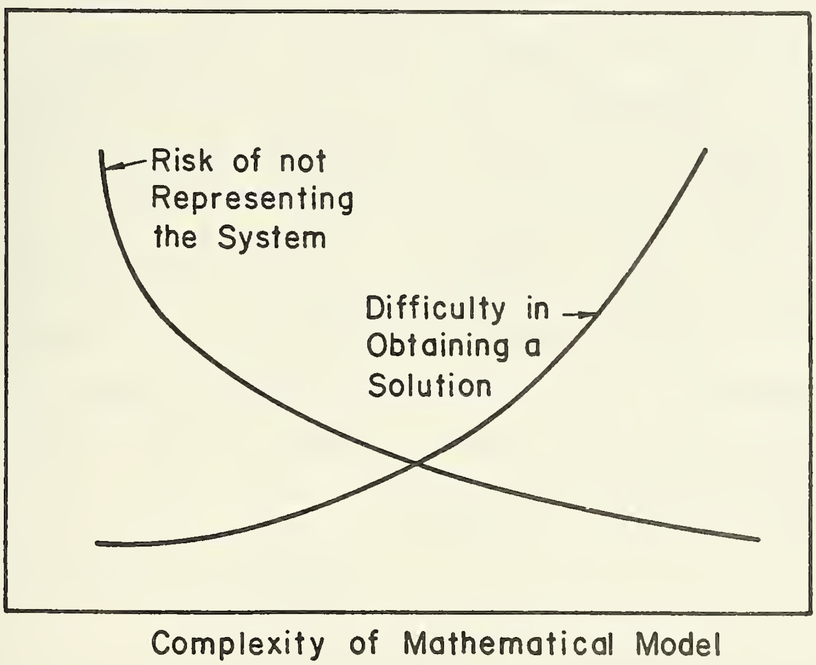


Figure 1. The model complexity trade-off diagram (after Overton and Meadows, 1976).

The physical processes governing watershed and river responses are very complicated. Many past studies have utilized a statistical interpretation of observed response data. The unit hydrograph method for water routing, the Universal Soil Loss Equation for soil erosion and the hydraulic

equations for stream morphology are examples of these types of studies. It is often difficult to predict the response of a watershed to various watershed developments or treatments using such methods, because they are based on the assumption of homogeneity in time and space. Mathematically simulating the governing physical process is a more viable way to estimate the time-dependent response of watersheds and river systems to precipitation with varying land use and water resources development. By analyzing basic ecosystem processes and the impact of management activities on specific processes it is possible to predict the cause-effect relationships between management activities and ecosystem response. With the aid of systems analysis techniques, a desirable mix of management activities or land-use practices can then be selected taking into consideration both the environmental and resource goals that satisfy the concept of best management practices. This paper presents a brief overview of various watershed modeling efforts at Colorado State University under the general direction of the writers.

Physical process simulation models represent the system being modeled by decomposing it into its respective components. By dividing a system into its respective components, "lumping" of processes or parameters can be avoided. By simulating the selected phenomena through separate components, each individual process can be analyzed and refined or altered to meet the needs of the user. Consequently, as each process component is upgraded, the model becomes more representative of the physical system. Because they are physical process component models, the processes involved are similar between the models. Differences do exist between some components, making some models more complex or versatile than others. Basically two modeling approaches are utilized by the writers. The selected water and sediment routing approaches are: 1) high resolution watershed storm water and sediment routing and yield model, and 2) simplified watershed storm water and sediment routing and yield models. A number of other approaches are available, but research has shown that these contain the most sensitive physical processes.

The above general approaches share essentially the same basic physical process. The main differences are in the formulation, implementation and degree of detail that may be represented. The high resolution model was first developed by Li (1974) and subsequently published by Simons, Li, and Stevens (1975) and updated by Shiao (1978). The model routes storm

runoff water from overland flow surfaces and then through the channel system of a watershed. This is done using mathematical formulations of the water and sediment continuity equations, the flow momentum equation, and certain assumptions about the flow. This model is termed high resolution because it uses complex topographic information and a finite difference solution technique to solve for water discharge at selected times and points on the overland flow surface and channel system. The watershed for this model can be subdivided into numerous overland flow surfaces and the channel represented by several connected segments.

The simplified models in contrast to the high resolution model require a watershed to be represented by a channel and two contributing planes or a combination of two-plane and single plane watersheds connected by a channel system. This much simpler representation of the watershed geometry provides for easier application, but may create problems if the watershed is extremely nonhomogeneous or anisotropic. This model uses an analytic formulation to route water from the overland flow planes (Simons, Li, and Eggert, 1977, 1978). Use of the single two-plane one-channel model is warranted for watersheds that are fairly homogeneous and are subject to spatial constant rainfall. The multiple watershed model may be used for larger, more heterogeneous drainages that may be modeled as a group of differing, yet internally homogeneous, subwatersheds (Simons, Li, and Spronk, 1978, and Li, Simons, Fullerton, Eggert, and Spronk (1979).

As an extension of the multiple watershed model, a generalized planning model for evaluating alternative management practices was recently developed at Colorado State University (Simons, Li and Eggert 1979) for determining the non-point source pollution loading that includes: 1) sediment from surface erosion as well as channel bottom and bank erosion, 2) thermal energy, 3) dissolved oxygen, 4) forest litter, and 5) nitrogen and phosphorus compounds.

SPATIAL REPRESENTATION OF WATERSHEDS

Because most watersheds are nonhomogeneous in topography, soils, vegetation, and other features, it is necessary to segment each watershed into units which can be treated as being homogeneous. Similarly, the channel system in a watershed can be represented by one or more segments, each having a characteristic location, shape, slope, and roughness.

The location, area, length, and slope of each watershed unit is usually obtained from the available topographic maps. The following steps can be used in collecting the geometric data from topographic maps. Two types of watershed segmentation are considered. For the high resolution model, the watershed is subdivided into square grids of a selected size (Simons, Li and Ward, 1978). The size of these grids or cells is chosen to conform with the watershed geometry and represent the accuracy of the input data and required output. Node points of the grid system represent sampling points where topographic, soils, and vegetative data are selected. The channel system is represented by straight line segments between node points. The sampled information is computer processed to produce a segmented watershed of overland flow cells with corresponding length, slope, width, and soil and vegetative indices, and a channel system described by lengths, slopes, and locations. Gravity flow logic, cell and channel aspect is used to determine flow directions in the watershed. On a much smaller scale, the slope, lengths, widths and flow directions of roadways can be prepared from maps, construction plans, or field measurements. For the simplified watershed models consisting of planes and channels, a different approach is used to abstract the geometry for model input. This approach can be used on small or large watersheds. On large watersheds multiple sets of two plane-one channel watersheds may be present (Simons, Li, and Spronk, 1978). A method is presented below that is applicable to single watersheds or subdivided watersheds.

Geometric Representation for High Resolution Model

The first problem encountered in numerical modeling of watershed response is to determine representative response units for mathematical computations. Simons, Li and Ward (1978) have approached this problem by developing a watershed segmentation program based on a grid system. The grid size is chosen so that the watershed boundary and channel segments can be approximated by grid lines (Figure 2). The overland flow units are the grid units inside the watershed boundary and the channel units are segments of channel between grid intersection points.

From the contour lines, the elevations of the land surface at the grid points are determined (Figure 3). These elevations, along with the locations and bed elevation of the stream channel, are input to the developed computer program. In addition to elevation data, vegetation and soil

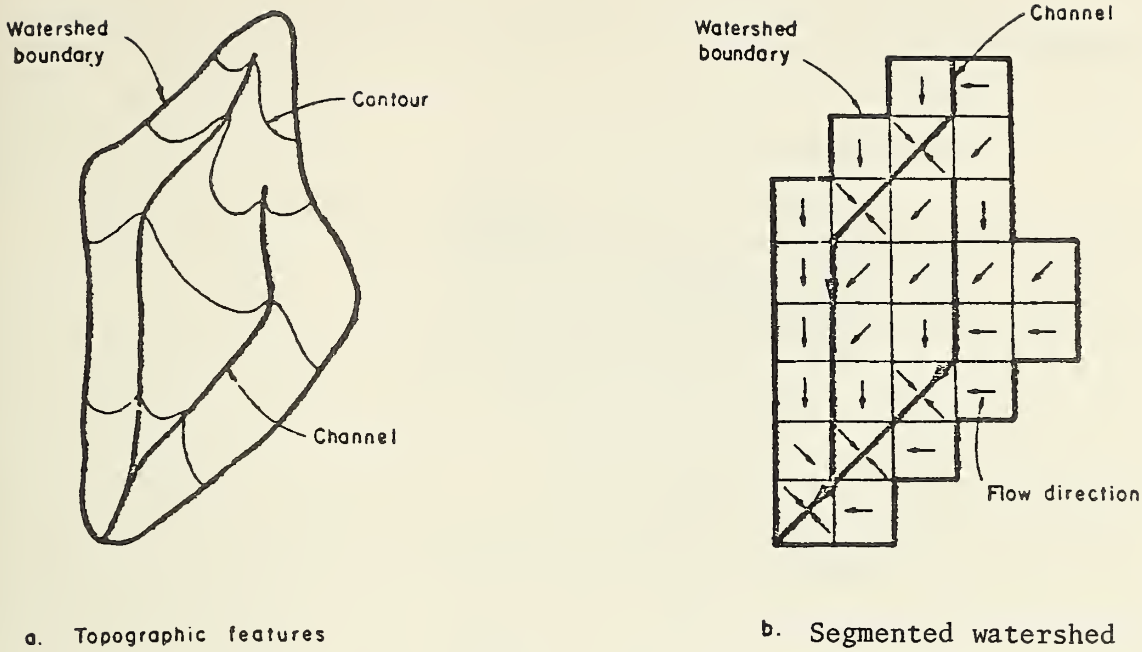


Figure 2. Example of watershed segmentation.

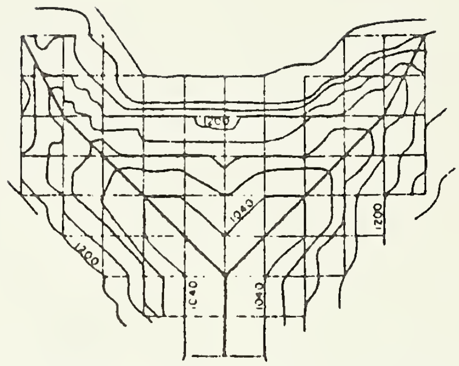
code numbers can be input for each grid point (Figure 3). The computer program then performs the following functions:

1. The slope and the slope azimuth of each overland flow unit are computed.

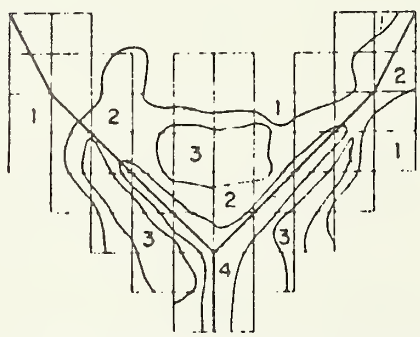
2. It is assumed that the water flows in the opposite direction of the slope gradient to the next overland flow unit or to the adjacent channel. Thus, water cascades from overland unit to overland unit and then into the channel system. The program identifies the cascade sequence (arrows in Figure 2).

3. The computation sequence for the flow is established by the program. The method employed is simply to follow the logics of gravity flow and flow continuity.

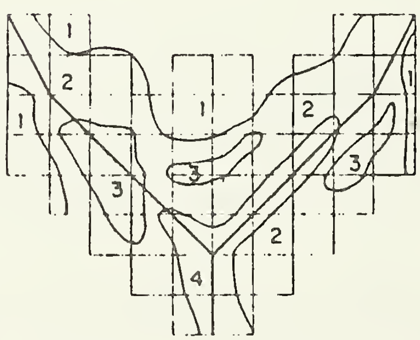
4. If data on the vegetation type, soil type, canopy cover density, and ground cover density are available, the variations of these factors inside a watershed can be established in the program. This is executed by decoding the vegetation and soil codes and assigning previously input parameters to each type code. These parameters may include soil porosity, soil depth, and selected vegetation measures.



(a) Topographic Map Contour Interval = 40'



(b) Soils Map Numbers are soil type codes



(c) Vegetation Map Numbers are vegetation type codes

Figure 3. Input data for hypothetical watershed.

In order to save computer storage capacity and processing time in the water and sediment routing computations, an additional computer program to combine small grid units into larger response units is developed. With this treatment, the flow is conceptually routed from overland flow units to channel units and to the selected watershed outlet.

This segmentation method is essential not only in water and sediment routing, but also for introducing the information from snowmelt computations, landslide hazard mapping, forest fire hazard mapping, forest inventory studies, and snow avalanche hazard identification into the routing model. Moreover, if such factors as soil properties, vegetation cover, type of management treatment, or rainfall vary within the watershed, these variations can be handled easily and with the least manual input by segmenting the watershed with a grid system. The developed segmentation method provides input data on watershed geometry and computational sequences required for the simulation model to predict water and sediment routing and yield from small watersheds.

Often the manual determination of the response unit is preferable for non-computer oriented personnel. Such a manual determination should follow the similar logic used in the computer segmentation method. The flow path can be drawn perpendicular to contour lines. The manual determination of hydrologic response unit is subject to the individual's perception and is time-consuming for applications to complicated watersheds. It is recommended that the manual determination be limited in application to small and simple watersheds or subwatersheds.

Geometric Representation for Simplified Model

The two types of simplified watershed simulation use essentially the same geometric representation. The watershed must be subdivided in such a manner to allow approximation of the land surface by planes that extend to the watershed boundary and one or more interconnecting channels. The simpler of these two models uses an "open-book" representation wherein the watershed is transformed into a single two-plane unit with a central channel. The more complex model uses a number of such units in combination with single planes and interconnecting channel segments. At Colorado State University these two simplified models have been developed. The basic method of transforming the contour map geometry into planes and channels, however, is the same for both models. This technique is described below for the "open-book" representation and then extended for the multiple

watershed case. The process is illustrated by Figure 4 and presented in a step-by-step form below.

1a. Divide the watershed into units which can be considered homogeneous by using the available topographic, soil type, and vegetation type maps for the watershed. The size of the division is based on the resolution needed and the availability of data.

1b. Divide the watershed using the channel system. This division is often at the user's discretion, but should be based on homogeneity in the channel segment or its contributing side slopes. This homogeneity may be the channel segment gradient or similar soil types on the contributing side slopes.

2. Delineate the main channel in the unit. Extend the channels at least to the last distinct end points. Such an end point is often noted as the last distinct "V" on the contour line for tributary channels. In small watersheds determining the correct path along which to extend the channel may be difficult. In larger watersheds the extension of the channel may be apparent all the way to the basin boundary. Therefore, the extension of the channel for measurement purposes is arbitrary. A general consideration may be:

(a) Small watersheds - Extend the channel to the last distinct "V" and no further.

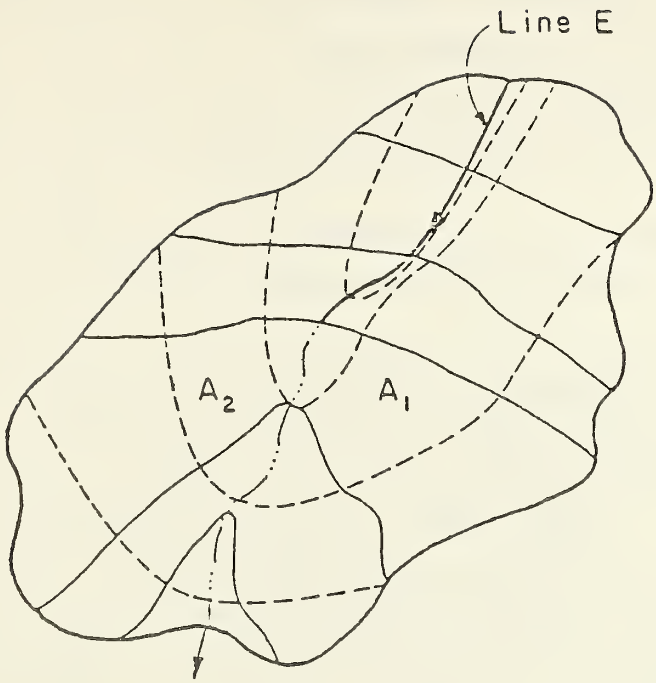
(b) Medium sized watersheds - Extend the channel from the last "V" one-half the distance to the watershed boundary.

(c) Large watersheds - Extend the channel from the last "V" to the watershed boundary.

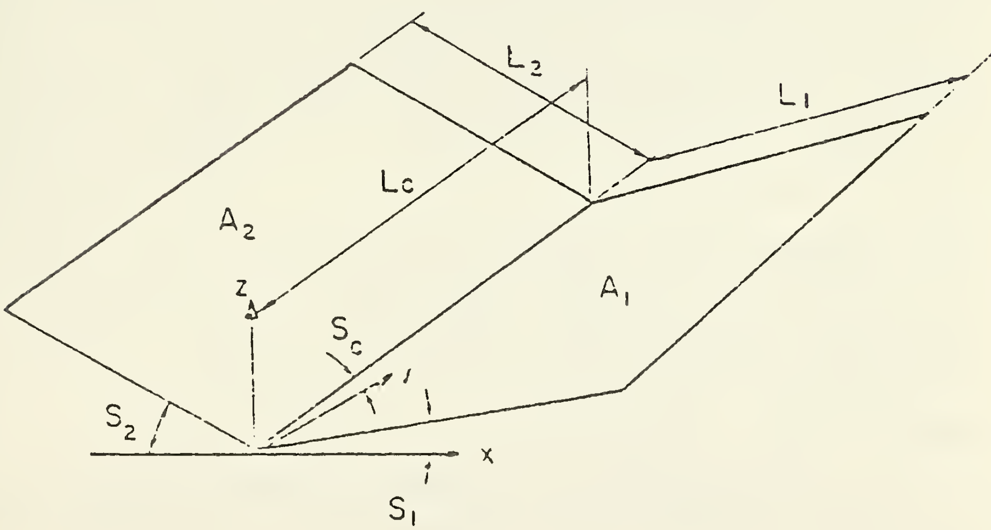
No distinction is made on watershed size as this is a factor that is dictated by experience. In general, however, a small watershed may have a maximum size of one hundred acres, medium would be 100 to 1,000 acres, and large, anything more than 1,000 acres.

If a channel extension is made, the extension must perpendicularly cross the contour elevations to insure that the water is following the shortest path to the channel. Measure the channel segment length.

3. Sketch in the boundaries between contributing side slopes to the different channel segments. The enclosed contributing areas are now the watershed subdivisions. Each channel has a left and right subdivision when looking downstream.



(a) Original Subwatershed Topographic Map



(b) Openbook Plane Representation

Figure 4. Geometric representation of a subwatershed unit.

4. Determine the channel segment slope as the ratio of elevation difference at the channel end points to the channel length.

5. Determine the area of the left and right contributing subdivisions by using the channel as the dividing line. For small and medium sized watersheds, an artificial dividing line may need to be constructed as an extension from the assumed channel end point to the watershed boundary. Make sure this division remains perpendicular to the topographic contours.

6. Determine each subdivision width as sum of subdivision area divided by channel length as determined in Step 4.

7. Subdivide the channel into several (5-20) equally spaced sampling points. At each sampling point lay out sampling lines from the channel to the watershed or response unit boundary. Sampling lines are drawn perpendicular to contour lines and represent flow lines that cross equipotential lines in a flow net. The sampling lines are the potential routes water would follow when flowing across the subdivision. Determine the slope as elevation change on the sampling line. Form the product of sampling line length times slope. Sum these products for the sampling lines in each response unit.

8. For small or medium sized watersheds, a single slope sampling line will be extended from the end point of the channel. This sampling line should coincide with the artificial dividing line constructed in Step 6. Because the area above the assumed channel endpoint represents an overland flow plane, it is treated as being equally divided between the two response units. To do this, add the slope-length products for this sampling line to the summed slope-length products for each subdivision. Also add the length of the sampling line to the summed lengths of the sampling lines of each subdivision. These additions will incorporate the effects of this headwater overland flow plane into each of the subdivisions.

9. Determine the average slope of each subdivision as the summed slope-length products for the unit divided by the summed sampling line lengths.

The multiple watershed model classifies the single plane units as planes and the "open book" units as subwatersheds. Storm water runoff hydrographs from the subwatershed units serve as inputs to the interconnecting channel units. Water in the channels is routed by using a

numerical solution to the nonlinear kinematic wave approximation. A method to account for channel losses due to infiltration is included in the channel routing procedure. The necessity of using a numerical channel routing routine rather than an analytical routine is due to the occurrence of kinematic shock. The analytical solution cannot be applied in situations where kinematic shock occurs.

There are four types of response units in the multiple watershed model: 1) a single plane unit, 2) an "open book" subwatershed unit, 3) a channel, and a connection. A connection unit is used when only the lower part of a basin is being modeled and the response of the upstream portion of the basin is input as a hydrograph recorded or simulated. As an example of the transformation of a larger, more heterogeneous watershed into a system of planes and channels, Figure 5 shows a map of Walnut Gulch, Arizona, a watershed selected for development and testing of the multiple watershed model. The boundaries of the planes and subwatersheds are marked to illustrate how a large watershed can be represented by a system of these units interconnected by channel units. Figure 6 shows a schematic diagram of Walnut Gulch Watershed, represented by planes, subwatersheds, and channels.

MODEL COMPONENTS

As mentioned earlier, both the high resolution and simplified models contain essentially the same physical process components; however, the implementation of the process varies considerably due to the differences in water and sediment routing methods. The components and basic model structure are presented below.

High Resolution Model

Once the watershed has been numerically defined by the above segmentation procedure, overland flow units and channel flow units in the watershed can be determined. Simons et al. (1975) developed a watershed sediment model which is primarily applicable for surface erosion simulation. They simulated the land surface hydrologic cycle, sediment production, and water and sediment movement on small watersheds. Conceptually the watershed is divided into an overland flow part and a channel system part. Different physical processes are important for the two different environments. In the overland flow loop, processes of interception, evaporation, infiltration, raindrop impact detachment of soil, erosion by overland flow, and overland flow water and sediment routing to the nearest channel are

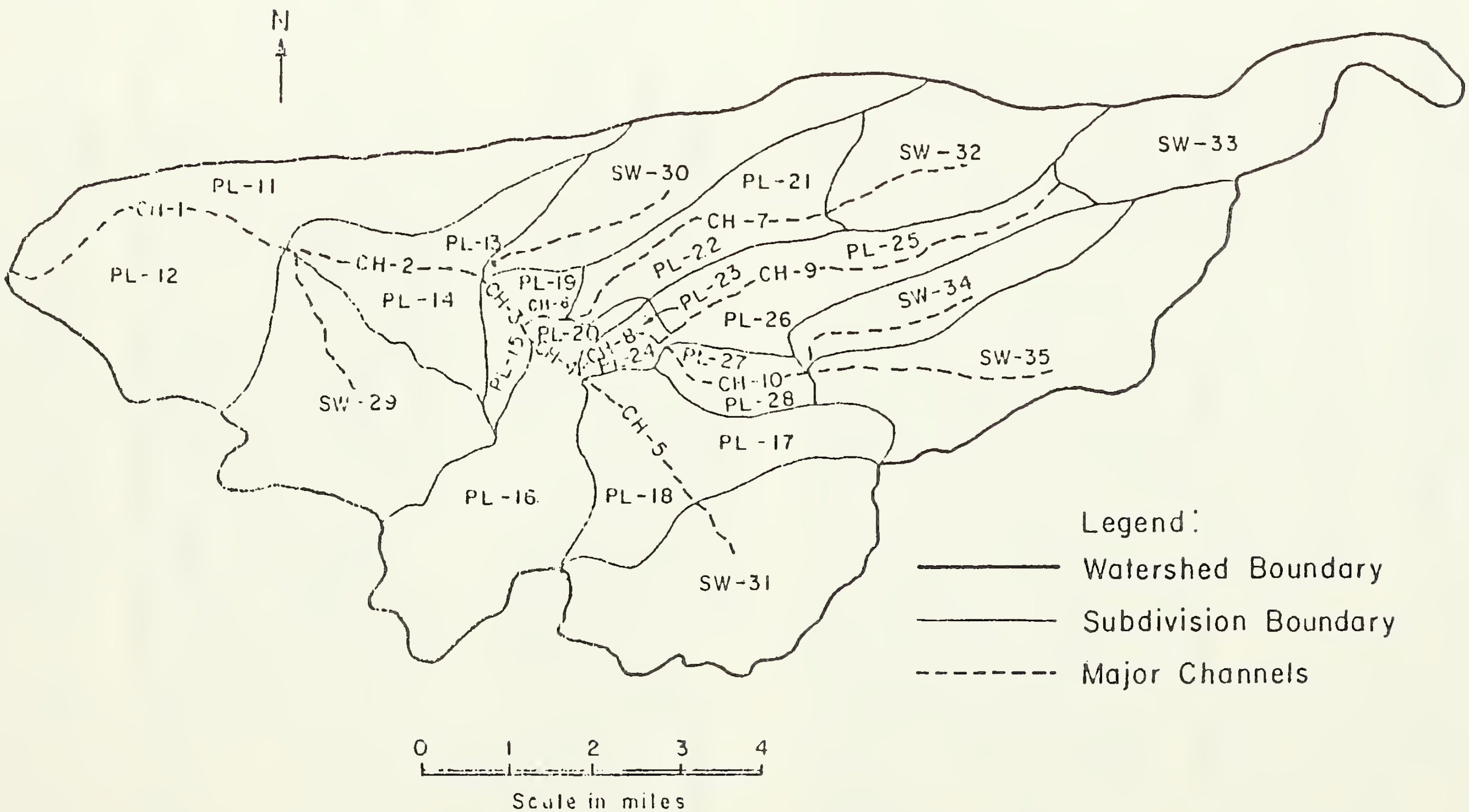


Figure 5. Response units for Walnut Gulch, Arizona, watershed.

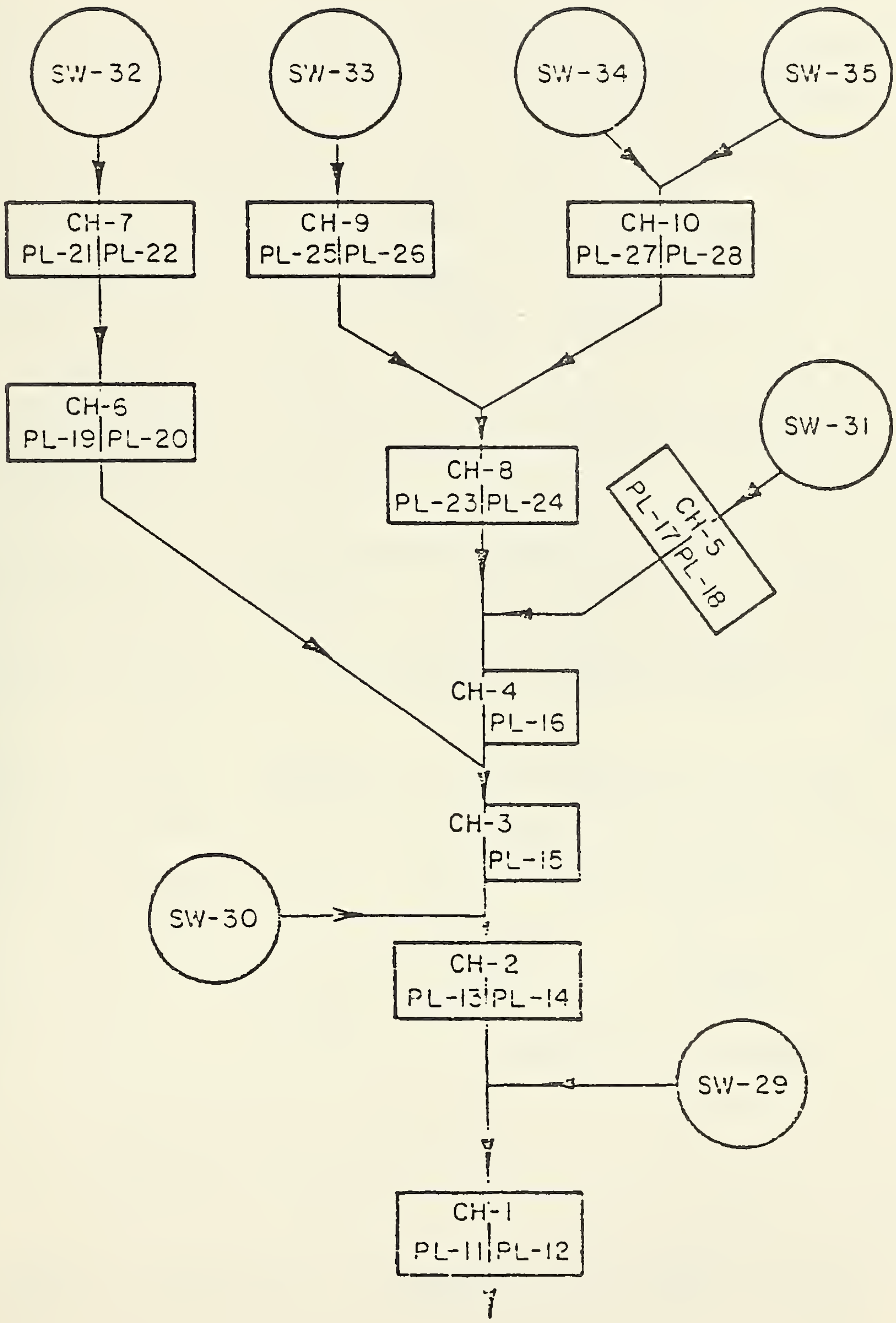


Figure 6. Schematic diagram of the Walnut Gulch response units.

simulated. In a channel system loop, water and sediment channel erosion or sediment deposition through the channel system is determined. A flow chart presenting the interrelationship of these processes is shown in Figure 7. A brief summary of the components is given as follows.

Overland Flow Loop

There are four components in the overland flow loop: interception, infiltration, overland surface water, and overland flow sediment routing.

Interception Component: In this component the interception amounts due to the crown and forest floor are computed and the net rainfall is determined from the rainfall input. The interception loss includes the constant interception storage and the continuous evaporation from the interception surfaces. The evaporation is usually negligible during the storm. The interception storage is formulated to be a function of canopy cover density, ground cover density, and vegetation type.

Infiltration Component: This component of the model simulates the process of infiltration. The infiltration rate is computed by an approximation of Darcy's Law assuming that a distinct wetting front exists and is formulated to be a function of saturated hydraulic conductivity, average capillary suction pressure, soil porosity, antecedent moisture content, and moisture content in the wetted zone. The rate of rainfall excess can thus be determined from the net rainfall and infiltration rates.

Overland Surface Water Routing Component: With this component the overland surface water runoff resulting from the mean rainfall excess is routed to the nearest channel. The routing procedure is based on the continuity of water, a momentum equation of kinematic wave approximation, and a set of resistance functions for different hydraulic conditions. The total resistance to flow is assumed to be a sum of the drag resistance due to ground cover and the shear stress acting on the soil bed. The computation is carried out by a nonlinear finite difference scheme developed by Li et al. (1975) and the computation results include the mean flow depth, bed shear stress and flow discharge at computation points as a function of time and space.

Overland Flow Sediment Component: The component of the model computes the amount of soil detachment by raindrop splash and by overland flow, the amount of wash load pickup and transport by surface runoff, and bed-

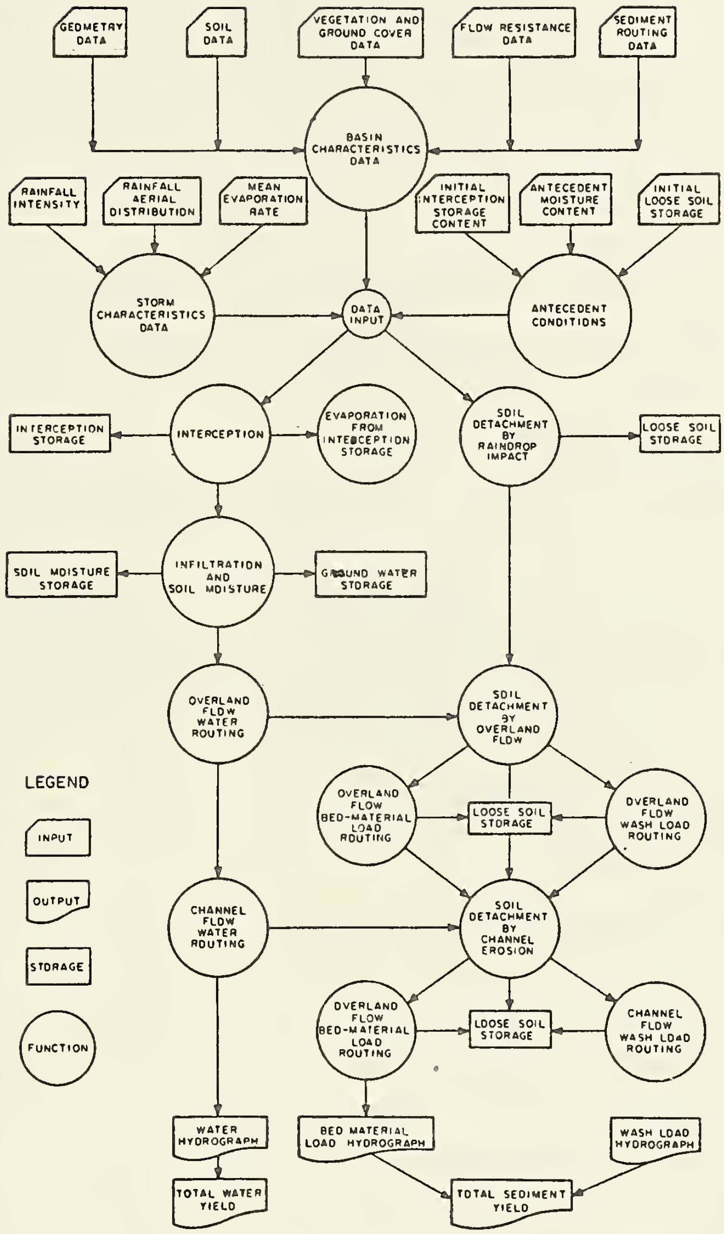


Figure 7. Flow chart for the watershed sediment and routing model.

material load movement. The amount of soil detachment by raindrop splash is assumed to be a simple power function of rainfall intensity. The soil detachment by surface runoff is considered as the result of bed-material load movement. The local transporting capacity of bed-material load is assumed to be a function of local effective bed shear stress and a combination of Meyer-Peter, Müller bed load equation and Einstein suspended load procedure is used for the sediment transport equation. The wash load pickup rate is formulated to be a function of bed shear stress and the available amount of loose soil. The sediment routing procedure is primarily based on the continuity equation for sediment (wash load and bed-material load), and the computation is carried out by a finite difference numerical procedure coupled with the overland surface water routing.

Channel System Loop

The channel system loop routes water and sediment contributed from all overland flow areas through the channel system, and computes degradation and aggradation in the channels.

Channel Water Routing Component: The component of the model routes the water down the creeks in the channel system and computes the hydrograph at the watershed outlet. The lateral water inflows to the channel system are the overland surface water flows. The channel water routing procedure and the finite difference scheme are similar to those used in the overland flow loop.

Channel Sediment Routing Component: With this component, the wash load and bed-material load are routed through the channel system. The computation results include the wash load and bed-material load hydrographs and the total sediment yield at the watershed outlet. The procedures of routing wash load and bed-material load are similar to those used in the overland flow sediment routing. The amount of degradation and aggradation in the channel system is determined by using the continuity equation for sediment.

Simplified Models

The simplified models contain the same physical processes listed above, but these model components are applied to subunits that are in general much larger than those of the high resolution model. In addition, these components are uncoupled in the sense that they are used to calculate the process response for the entire event on a given unit before passing

on to the next physical process. For example, infiltration for the entire storm is calculated before passing the entire rainfall excess function on to overland flow routing. This is as opposed to the time step by time step calculation of the high resolution model. Therefore, some resolution is sacrificed for a gain in computational speed.

The physical processes modeled for each type of unit are shown in Table 1. The processes involved in the plane and subwatershed units are

Table 1. Physical Processes Considered for Each Type of Unit

	Plane	Subwatershed	Channel
Physical Processes	1. Interception	1. Interception	1. Channel Infiltration
	2. Overland Infiltration	2. Overland Infiltration	2. Numerical Channel Routing
	3. Analytical Overland Routing	3. Analytical Overland Routing	
		4. Analytical Channel Routing	

identical except for the analytical channel routing performed for the subwatershed units. The only processes considered for the channel units are numerical routing and channel infiltration.

Much of the rain falling during the first part of a storm is intercepted by the vegetal ground cover. Precipitation intercepted by vegetation or other ground cover eventually evaporates, and the amount of rainfall reaching the soil surface is less than the recorded amount. The amount of interception loss depends on the percentage of the ground that is covered by canopy and ground cover, and their respective water holding capacities. It is assumed that interception starts at the beginning of a storm and continues until the potential intercepted volume is filled.

A portion of the rainfall reaching the ground moves through the soil surface into the soil. This process is defined as infiltration. The model used to simulate this process is based on the Green and Ampt infiltration equation (Li, Simons and Eggert, 1976).

Using an approximate explicit solution to the Green-Ampt equation for time varying rainfall given by Eggert, Li and Simons (1979), a function for infiltration with respect to time is developed. Thus, the infiltration occurring during a selected time period can be determined if the soil characteristics are known.

An analytical solution to the continuity, momentum, and cross section geometry equations is used to route water in the plane and subwatershed units. The method presented is identical to the routing scheme presented by Simons, Li, and Eggert (1977). However, the routing of water with the conditions of continuous infiltration is developed and incorporated. Due to the assumed "open book" geometry, both overland and channel routing are required. Excess rainfall, the amount of rainfall not intercepted or infiltrated, serves as the input to the overland flow routing scheme. Results of the overland flow routing are then used as the lateral inflow into either a subwatershed or a channel unit.

The partial differential equations for overland flow are solved by the method of characteristics. The characteristic paths along which the solution is valid can be calculated in either the upstream or downstream direction. This allows a user to find the discharge at the downstream boundary for any given time.

A numerical procedure for water routing developed by Li, Simons and Stevens (1975) is used for the channel units. Routing is accomplished by a second-order nonlinear scheme developed to numerically solve the kinematic wave equation. A numerical routing procedure rather than an analytical procedure is used for the channel units because analytic solutions are restricted by the formation of kinematic shock. Kinematic shock results when characteristic paths intersect. Physically this may be described as a faster moving parcel of water overtaking a slower moving parcel of water as they both travel downstream. Analytic solutions for problems that have kinematic shock display discontinuities in the hydrographs. Due to this restriction, a simple numerical routing procedure is necessary for the channel units.

Stability of a numerical procedure refers to whether the computational errors, due to the finite difference approximation of the partial differential equations, accumulate to an unbounded error. If the errors do not grow unbounded, the procedure is stable. The numerical scheme that

is used has proved to be unconditionally stable and can be used with a wide range of time to space increment ratios without loss of significant accuracy. However, the physical significance of the time and space intervals should be considered when selecting their values.

An infiltration routine is combined with the numerical channel routing procedure to account for channel seepage losses. The channel infiltration procedure is similar to the overland infiltration procedure because both are based on the Green-Ampt infiltration equation (1911). The major difference between the two routines is that the depth of the water in the channel situation cannot be neglected as in the overland situation.

In addition to the continuity equation for water and momentum equation, additional equations are refined for sediment routing. Of primary importance is the sediment continuity equation and corresponding sediment transport formulae. Another basic principle is that sediment yield is directly proportional to either transport or supply. In general, if supply is greater than transport capacity, the transport capacity controls yield and vice-versa. Sediment supply is considered to be from raindrop impact detachment and flow detachment. The basic equations are applicable to overland and channel flow. Another important aspect is the use of the sediment continuity equation to keep account of aggradation or degradation of the land or channel surface. In all models, sediment yield is considered for the individual size fractions.

Generalized Planning Model

The model presented in this section contains the following specific hydrologic components: 1) daily water balance, evapotranspiration and vertical soil water movement, 2) water routing in watersheds and channels, 3) sediment routing in watersheds and channels, 4) thermal loading, 5) dissolved oxygen loading, 6) forest litter loading, and 7) nitrogen and phosphorus loading. The model will be addressed specifically to forest activities involving timber harvest, timber planting and replacement, grazing, mechanical site preparation and prescribed fire. Alone or in combination, these activities constitute the substance of many planned management practices in the forest environment.

Water Balance

Since infiltration exerts a fundamental control on the storm water runoff hydrograph, any long-term hydrologic simulation must have a component for calculating the changes in soil moisture content as a function

of time. The primary processes affecting the amount of soil moisture are infiltration, percolation, evaporation, evapotranspiration and drainage. These interrelated processes involve hydrologic, biologic, atmospheric and soil-specific aspects. Therefore, a physically-based water balance model must simulate all of these aspects and properly account for their interrelation. After a literature search for an existing water balance model, a decision was made to modify and implement a simulation presented by Goldstein and Mankin (1972). This program, known as PROSPER, has been widely tested in a variety of locations with generally good results (Swift et al., 1975; Luxmoore et al., 1977), particularly in the deciduous forest biome. The success of these applications is probably based on the flexibility built into the model. It is possible to adapt model subroutines to a particular watershed environment by modifying the methods used to calculate the resistances to water flux through the soil and plant components.

PROSPER is a plant-atmosphere-soil water flux simulation which implements an energy balance and aerodynamic calculation of evapotranspiration using the Penman method with a multilayer Darcian soil model. The model simulates the fluxes of water through the soil and plants in response to atmospheric and solar conditions. The simulation presented by Goldstein and Mankin (1972) uses a time increment of one day. All hydrologic plant and atmospheric processes are averaged on a daily basis. The model as implemented uses an electrical circuit analogue for the soil and plant system. The current in the circuit loop represents the water flux through the respective soil, plant, or atmospheric component.

Since PROSPER was written for predicting daily variations in water flux, its formulation is inadequate for the prediction of infiltration and interception on a storm-by-storm basis. Further, since the time history of infiltration during a storm is particularly critical when determining water and sediment runoff, the effects of watershed management on infiltration parameters could not be properly simulated without modification to PROSPER. Therefore, the water balance component was modified to include a layered soil infiltration component for more precise determination of storm water runoff and a storm water interception routine. Both infiltration and interception components provide greater sensitivity to management activities in the watershed than the original PROSPER, and the

infiltration routine provides for the interfacing of the water balance component with the water and sediment routing and water quality subprograms.

Water and Sediment Routing

The water and sediment routing model is designed to route storm water and sediment runoff from watersheds of complex geometry. In order to accomplish this task, the complex watershed geometry must be simplified into a representation suitable for computer simulation. The geometric approximation used in this component is an arbitrary number of two plane, one-channel "open book" subwatersheds and planes linked together by channels.

For simplicity a numerical solution to the kinematic wave problem could have been used for both the subwatershed units and the linking channels. However, an analytical solution such as the method of characteristics approach allows more efficient use of computer storage and usually more rapid calculation of the runoff hydrograph. Therefore, whenever possible, analytical solutions are employed. To be consistent, in the portions of the watershed where the analytical method is used to route the water, the sediment yield is also computed by an analytical method. Likewise, in the portions where water is routed numerically, the sediment yield is computed by a numerical routing scheme. Details of the multiple watershed water and sediment routing model were given earlier.

Nutrient Routing

Nutrient elements are a source of non-point pollutants affecting water quality. Two of these elements, nitrogen and phosphorus, are of concern because of their role in eutrophication processes. A physical process simulation model was developed for predicting nutrient losses from forest and agricultural watersheds associated with surface runoff and sediment transport.

Mass balance and loading function concepts were the basic principles utilized in formulating this model. The model was developed to predict loadings of organic nutrients, nitrate, ammonium, and inorganic orthophosphorus to streams and rivers.

Natural nutrient input to the ecosystem comes mainly from precipitation, litter fall, and geologic weathering. Precipitation and litter fall were considered the primary external inputs of nutrients from the atmosphere. These average inputs were routed into the litter layer where

microbial degradation occurred. The products of degradation were then routed to the stream and into the soil layer. Within the soil layer, these products were again evaluated along with plant uptake and soil adsorption. The products of these processes occurring within the soil were then routed to the stream. Generally, nutrient constituents cannot move unless transported by sediment and water and therefore, water and sediment are the major carriers of nutrients through the ecosystem. Evaluation of these carrier amounts is necessary for predicting nutrient losses from the watershed.

The nutrient simulator proposed here is basically a nutrient budget model. All of the processes mentioned above except the immobilization process were taken into account when simulating average nutrient concentrations in the soil. The quantities of nutrient losses to streams during storms were predicted by the incorporation of the loading function concept.

Temperature and Dissolved Oxygen Routing

Thermal energy content, dissolved oxygen (DO), and biological oxygen demand (BOD) of runoff water can directly or indirectly affect the temperature and oxygen content in the stream. Based on mass and energy balance, the temperature and dissolved oxygen model is included in this simulation. This model is useful to evaluate the thermal and dissolved oxygen loading to the stream through surface runoff.

Overland flows transmit thermal and DO loading to the stream. Temperature and dissolved oxygen loading of the stream result from high temperature, high biochemical oxygen demand, and low dissolved oxygen in runoff water. Temperature and DO effects of subsurface flow are not included in this model.

The three mechanisms of heat transfer, radiation, conduction, and convection are included in this model. Each mechanism plays a role in the heat transfer process. Conduction is the only predominant mechanism for heat transfer between soil layers and heat transmission between soil and surface flow. Convective heat transfer occurs because of relative motion between various parts of the heated body or fluid. Convection plays an important role in heat transfer from water surfaces, particularly in evaporative processes. In this model these heat transfer mechanisms are

used to formulate equations for 1) atmospheric processes, 2) canopy-ground cover processes, and 3) surface runoff processes.

The oxygen concentration in the stream water at any given time is determined by the solubility of oxygen in the water, the rate at which this oxygen is consumed by various biological processes (represented by biological oxygen demand), and the rate at which this depletion is replenished.

Deoxygenation of the water due to the bacterial decomposition of carbonaceous organic material and reaeration caused by the oxygen deficit and turbulence are the most fundamental processes occurring in natural water. The basic theory used to describe the deoxygenation and reaeration processes was proposed by Streeter and Phelps (1925). The rate at which the BOD is exerted was presumed to be identical to that observed while using the laboratory BOD test. A proportionality is assumed to exist between the reaeration rate and certain hydraulic parameters of flow. The DO effects include concentration reductions due to purging action of gases rising from the benthal layer, plant respiration, diffusion into the benthal layer, and DO addition photosynthesis.

Streambank Erosion

A mathematical model of the process of streambank erosion by channel widening is included in this simulation. The predictive capability of the model is enhanced by its phenomenological structure, although empirical data are needed in the stream morphology component. The model estimates the total amount of streambank erosion and the fraction of it that goes into suspension. Threshold channel conditions, bank characteristics, and the hydrologic excitation are input to the model.

As formulated, the streambank erosion model estimates the total amount of erosion that is likely to occur in the transition from a condition of geomorphic equilibrium to another condition of equilibrium. As such, it does not provide information on the rate of streambank erosion; rather, it gives a total value assuming the new equilibrium condition is eventually reached. In practice, however, the rate of streambank erosion is a function of the time history of the hydrologic excitation which is not explicitly considered in the present model. Therefore, the calculated values are to be regarded as estimates of the total amount of streambank erosion that is associated with a certain level of hydrologic excitation.

Further refinements will need to be implemented if the model is to provide information on the rate of streambank erosion.

Forest Litter

A first approximation to the rill formation and the loading of forest litter is included in this simulation. The model is based on the assumption that the amount of forest litter loading is directly proportional to the areal extent of rilling. This is a reasonable assumption in view of the demonstrated effectiveness of concentrated flow in transporting sediment and debris through upland watershed drainage networks. This approach allows the conversion of the forest litter loading problem into that of determining the areal extent of rilling (rilling density), given a set of topographic, hydrologic, and morphologic conditions.

The quantity of forest litter delivered to a stream is a direct function of the areal extent of rilling and the amount of forest litter production. The areal extent of rilling will, in general, be determined by large events. Smaller subsequent events will not entirely fill the established rill network. Therefore, the litter washed out of the rill network will be detached from the area defined by the top width of the flowing water. This top width may be obtained from an "at a station" relationship provided by Li, Simons and Stevens (1976).

Sequential Goal Programming

The problem of management of a basin depends very much upon the selection of the best land-use strategy to optimize specified socioeconomic objectives under certain constraints on water and sediment transport conditions in the stream channels and on water quality standards in the basin. The quality of a basin management plan depends on the quality and availability of data. However, the efficiency of planning depends on the optimization tool to be selected and the accuracy of simulation models used to project future basin-system response. A review and evaluation of multi-objective programming techniques used to solve basin planning problems has been conducted by Loucks (1975) and later by Cohon and Marks (1975). One technique of increasing popularity often encountered in water resources literature is goal programming. It is designed to evaluate (possibly conflicting) goals as well as goals of differing priorities.

The planning model is designed as multi-level. The lower level is used to select optimal land-use strategies based on different alternative management practices and subject to some specified land-use constraints.

In this level, the elements of the resource response matrix are calculated by various land-use process models which use the same type of spatial and temporal information (i.e., same soil-vegetation units and time-step). After selecting a set of optimal strategies for land-use management, the upper level is then used to select the best management strategy for the entire basin system based on different land-use strategies selected from the first level and the outcomes of hydrologic and water quality component processes, subject to some specified socioeconomic constraints. In this level, complex models of water and sediment yields and water quality are used to calculate the elements of the process response matrix which then serves as the necessary input for the selection of the best basin management strategy.

The collected data and results of analysis for the generalized planning model will involve large quantities of information. The development of an efficient data storage and retrieval system is certainly necessary. A simple and flexible data storage and retrieval system has been developed by Simons et al. (October, 1978). A brief description of the system is given in Appendix I.

EXAMPLE APPLICATIONS

General

Responding to increasing demands for water for human survival, food production, and energy production requires effective tools for analyzing the ecological system response. Mathematical procedures are utilized in a wide variety of water resources planning applications, including flood control, nonpoint source pollution control, water drainage design, river training work, watershed improvement, stream bank erosion control, mine land reclamation, surface mining impacts, maintenance of navigable channel, road construction, pipeline crossing design, canal design, groundwater management, etc.

There are already numerous examples of successful applications of physical process simulation models of various watershed and river systems analysis and planning efforts and interest in utilizing such techniques is steadily increasing. The following are brief descriptions of the most significant examples of applications led by the Engineering Research Center, Colorado State University.

Degradation and Aggradation Analysis

Analysis of degradation and aggradation in a gravel stream bed should consider routing of sediment by size fractions, particularly where degradation is of prime concern. The application of models to the routing of sediment by size fractions has been successful. In the analysis of degradation below an emergency spillway in the T or C Williamsburg Watershed, New Mexico, such a technique was applied (Simons and Li,March, 1978).

The magnitude of scour was determined utilizing a sediment routing procedure that considered the size fractions of bed material. The computational procedure involved the use of a sediment transport equation, the sediment continuity equation, the armoring effect of coarse materials, and the channel geometry equation. Hence, the mathematical model was developed according to physical principles governing water and sediment transport, degradation and armoring processes. Both the local scour immediately below the structure and the general scour pivoting from a downstream control point were evaluated in the analysis. Figure 8 shows the time-lapse change of local and general scour. The local scour depth defined in this study is measured from the present bed level. This local scour depth represents a combination of general scour and local scour according to established definitions. In order to check the applicability of the mathematical model, a large-scale physical model (1:30) was utilized by a federal agency to estimate the local and general scour for the design freeboard hydrography. The results from both totally independent model approaches were extremely close, demonstrating a successful application of the technology of routing sediment by size fractions.

In the analysis of erosion and deposition problems associated with the Conrock gravel mining operation in the San Juan Creek and Bell Canyon of Orange County, California, a mathematical model for routing sediment by size fraction was again applied (Simons and Li, June, 1978). It provided an estimate of the erosion and deposition response of the stream and gravel pit subject to different hydrologic inputs. Three storms in January, February and March of 1978 induced significant degradation and the data available provided a test for the model. The simulation was made using time steps of four hours. The time lapse changes of elevation at the original gravel pit boundary (Station 16+00) is given in Figure 9 . The simulation results are excellent when compared with field measurements.

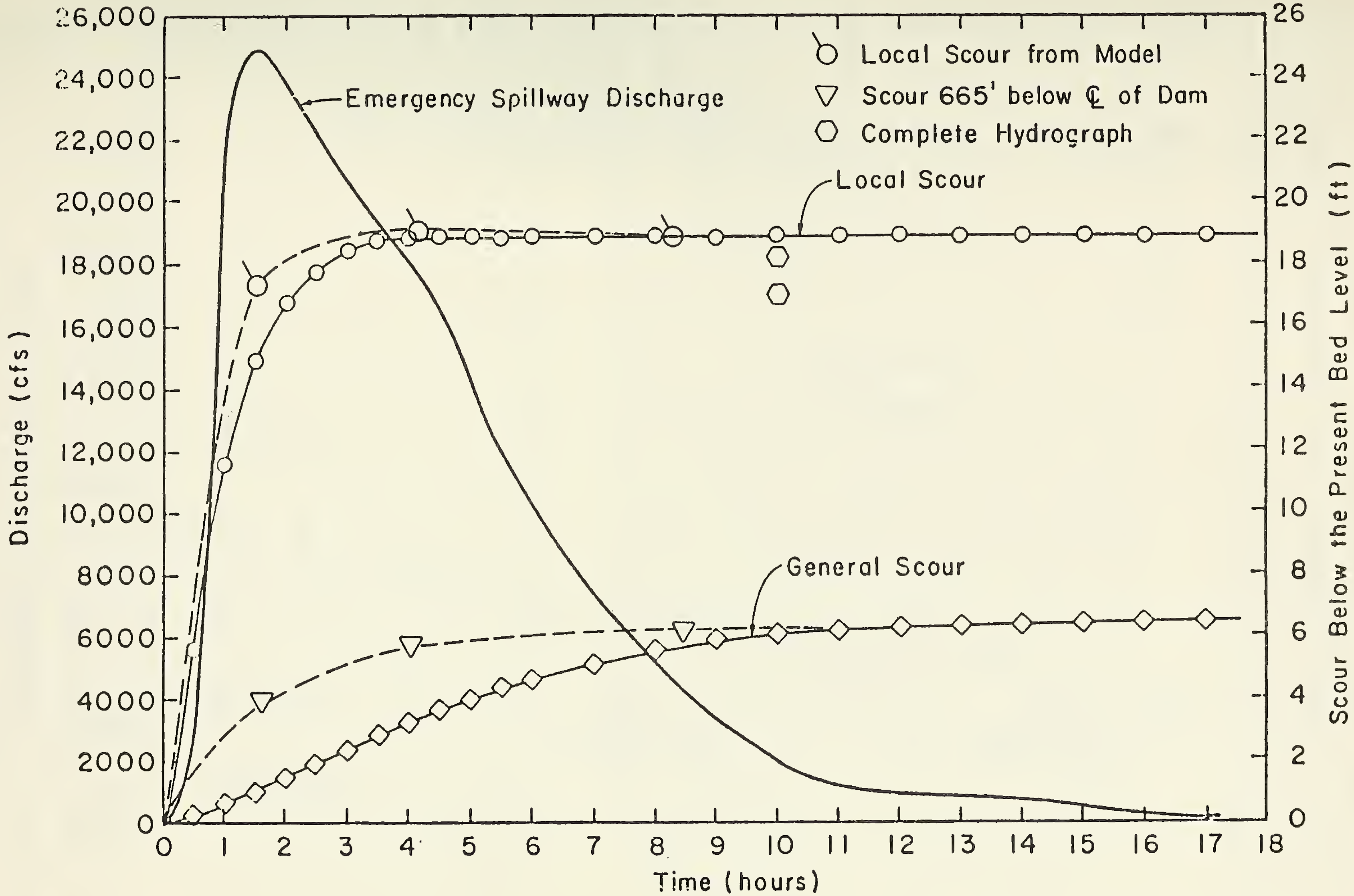


Figure 8. Local and general scour with the existing downstream control (6970 ft from the structure).

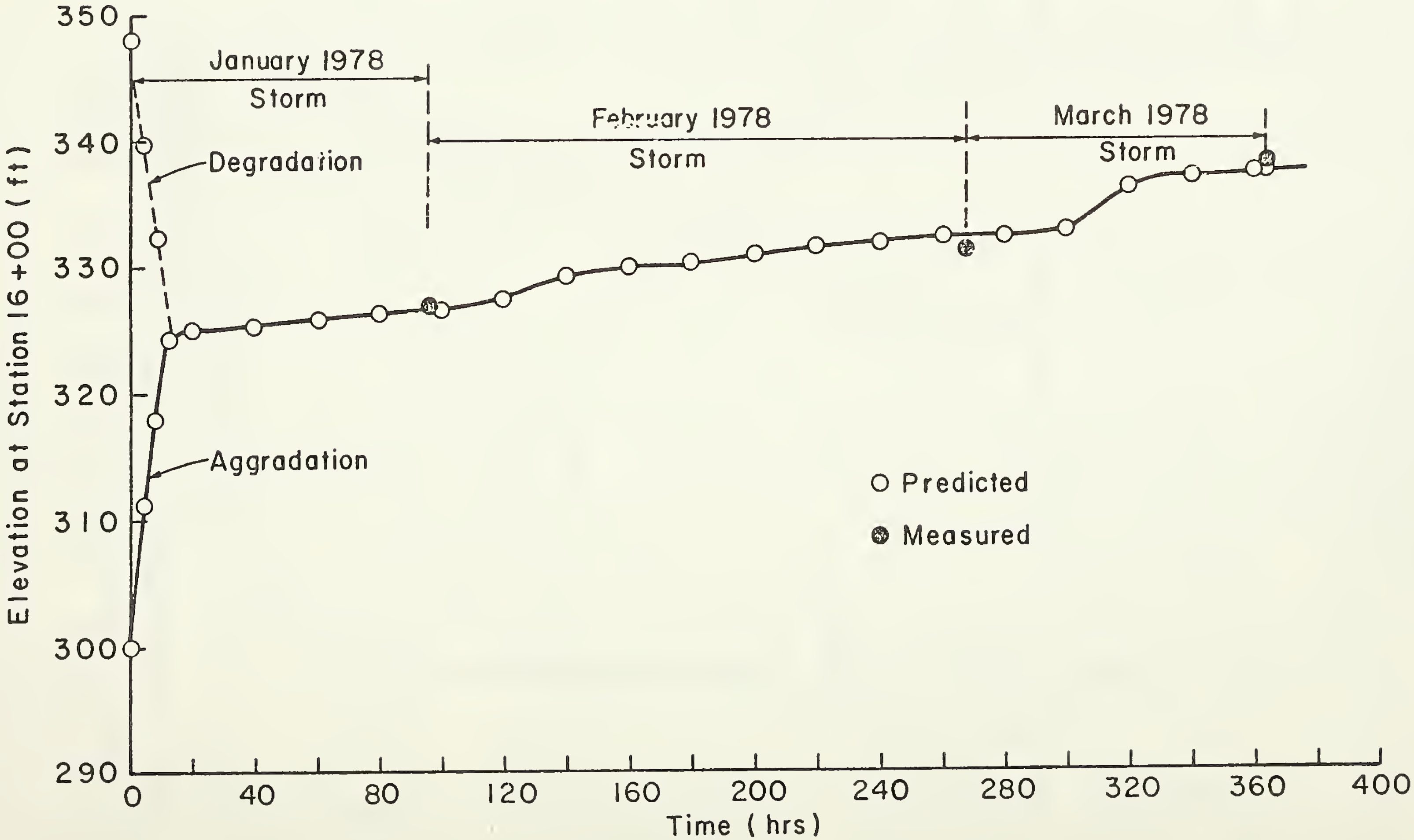


Figure 9. Time lapse changes of elevation at the original gravel pit boundary (Station 16+00).

One point worth mentioning is that the simulated results of the 1978 storms were predicted utilizing the calibrated sediment transport parameters based on the data from two 1969 storms. The mathematical model was then utilized to evaluate four differnet alternatives of gravel mining and rehabilitation plans.

Multiple Watershed Analysis

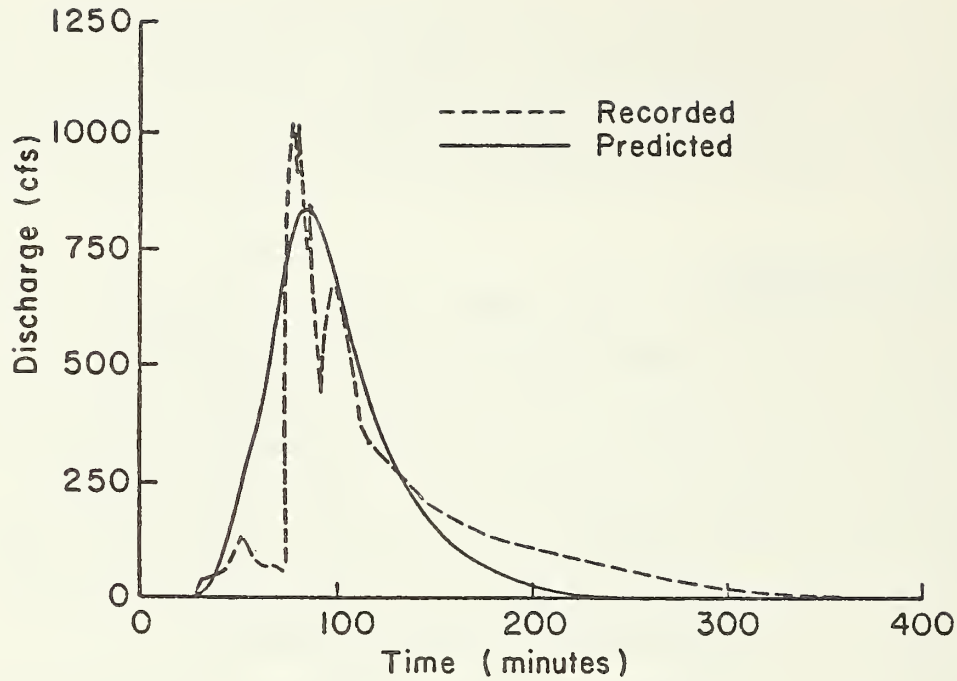
Legal and environmental concerns often encompass a large area. In order to analyze the total system, a multiple watershed approach is required. The multiple watershed model developed by Simons et al.(April, 1978) subdivides a large watershed into homogeneous response units as dictated by basin geometry and physical characteristics. The system of planes, channels, and subwatersheds developed are designed to represent an entire basin. The hydrographs from each response unit are simulated and then combined to obtain a hydrograph for the entire watershed.

The multiple watershed model was tested by comparing the predicted and measured hydrographs on the Walnut Gulch Watershed in Arizona. The runoff from six square miles was measured by flume number eight in the watershed. Figure 10 shows a comparison of recorded and predicted runoff hydrographs at flume eight for four different storm events. Agreement between the measured hydrographs and the simulated hydrographs is satisfactory.

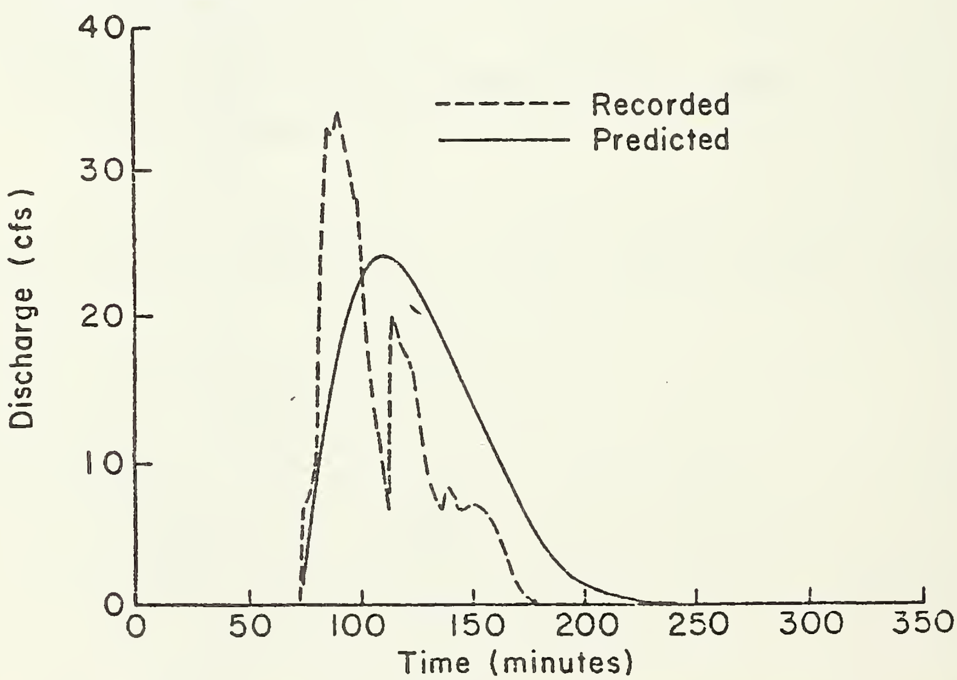
The entire Walnut Gulch Watershed (57.5 square miles) was then modeled for three different storm events utilizing the calibrated parameters based on the data for the six square mile watersheds. The drainage areas (approximately 5.5 square miles) for several stock ponds were not included in the analysis since spillage was assumed to be negligible. The rainfall distributions for the response units were calculated by using an isohyetal map and individual gage records. The comparison of the predicted and recorded hydrograph is shown in Figure 11. The agreement between predicted and recorded runoff is good considering the complexity and size of the watershed.

Stage-Discharge Relationships

The relationship between stage discharge is very important for the instream flow analysis. Most of the rivers, especially those with flatter channel gradients, have stage-discharge relations that have a hysteresis loop caused by dynamic effects or by other reasons. Simons, R. K. et al.(1977)

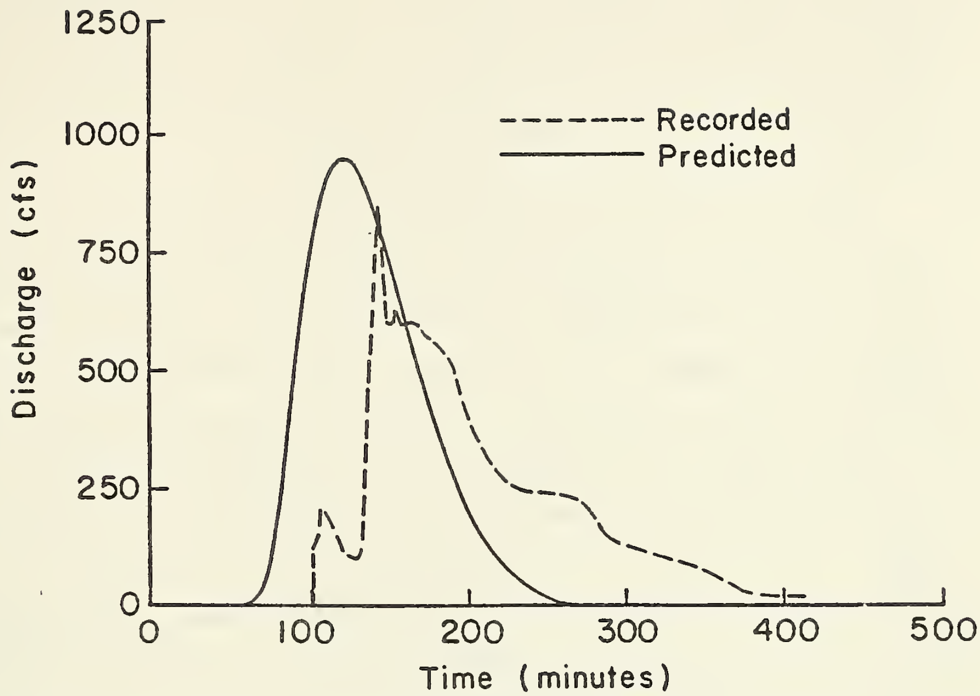


a. Runoff hydrograph for the storm of September 9, 1965, for Walnut Gulch flume #8.

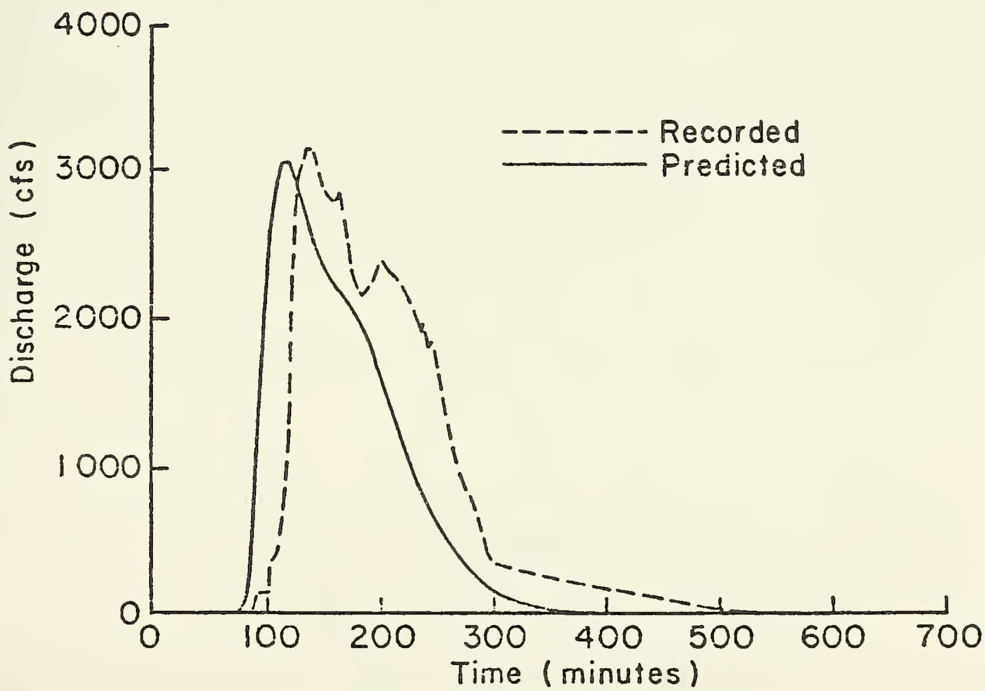


b. Runoff hydrograph for the storm of August 25, 1968, for Walnut Gulch flume #8.

Figure 10a,b. Runoff hydrograph for Walnut Gulch flume No. 8.



a. Runoff hydrograph for the storm of September 4, 1965, for the entire Walnut Gulch watershed.



b. Runoff hydrograph for the storm of September 9, 1964, for the entire Walnut Gulch watershed.

Figure 11a,b. Runoff hydrographs for the entire Walnut Gulch watershed.

presented a new approach to analyze the relation between flow stage and flood discharge. Their method was developed by utilizing a full dynamic equation considering the physical significance. Figure 12 shows that the observed and computed stage-discharge relations on the Mississippi River at Tarbert Landing are in close agreement.

Despite the existence of the looped stage-discharge curves, river stage is usually estimated either by statistical stage-discharge relationships or by using backwater simulation models. Frequency and magnitude of error associated with three models were examined by Li et al. (1979). The first model utilized is a statistical stage-discharge relationship. The second model is a steady flow, rigid boundary backwater model, and the third model is a steady flow backwater model with uncoupled sediment routing. The sediment routing model can compute changes in the channel due to aggradation and degradation. For thorough comparison, each model was applied to two case studies. One case involved a relatively stable reach of river, while the other was unstable.

The Yazoo River in Mississippi was selected for study due to the availability of data for that area. Two reaches of the river were carefully analyzed: a stable reach near Locopolis and an unstable reach at the Fort Pemberton cutoff near Greenwood. Historically, the bed elevation in the stable reach has not changed substantially. However, the bed of the unstable reach degraded up to 30 feet during 1973 and 1974. This degradation was caused by the removal of a dam in the cutoff that allowed a large portion of the Yazoo River flow to bypass the Greenwood Bendway. The changing behavior of the river discharge and sediment transport at this unstable reach makes prediction of flood stage from discharge data difficult. This is especially true for models that are based entirely on historical data since they cannot adjust to the new flow conditions. Selection of these two reaches allows evaluation of the reliability of the three models.

All three models were calibrated using the same data. To verify the results of the model's capability, additional computations utilizing data independent of calibration data were made for each model using the calibration results. For comparison purposes, model error is defined as the difference between observed and predicted stage for each day. Figures 13 and 14 show the relative frequency distribution of verification

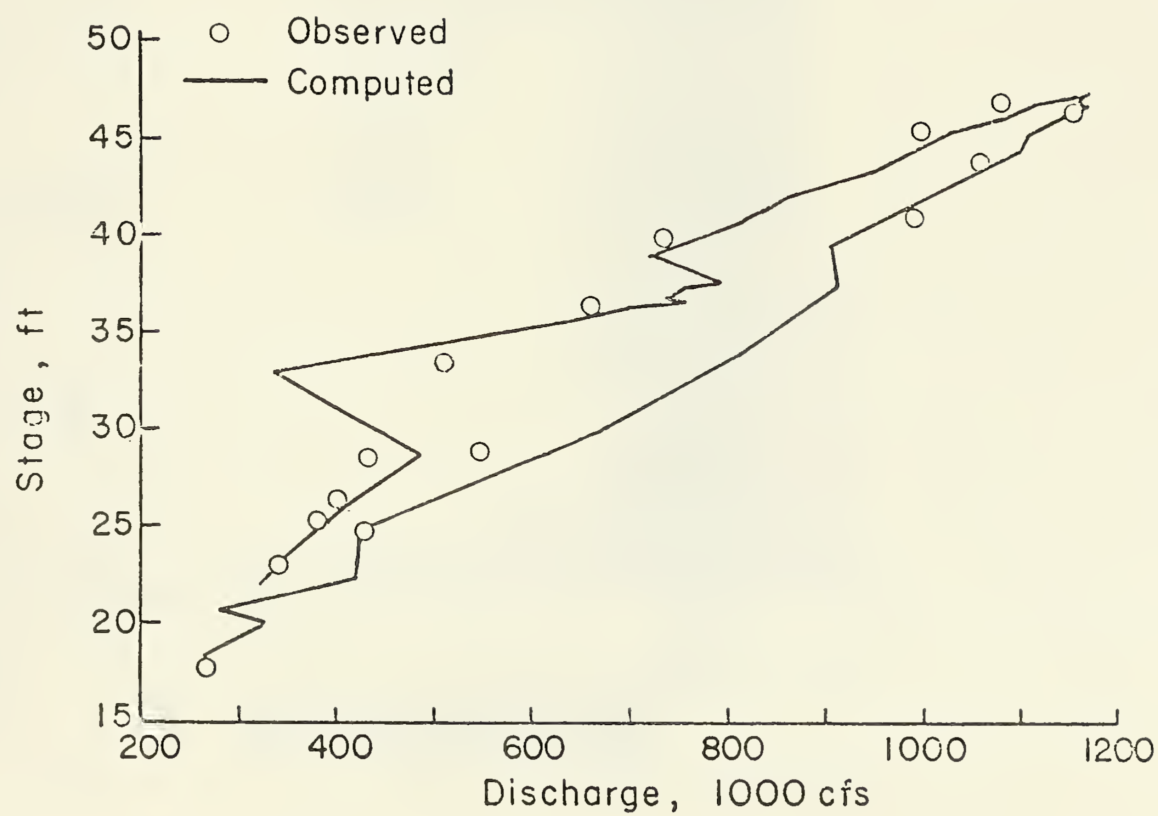


Figure 12. Stage-discharge relation for Mississippi River, Tarbert Landing, LA (2/9/66-4/11/66).

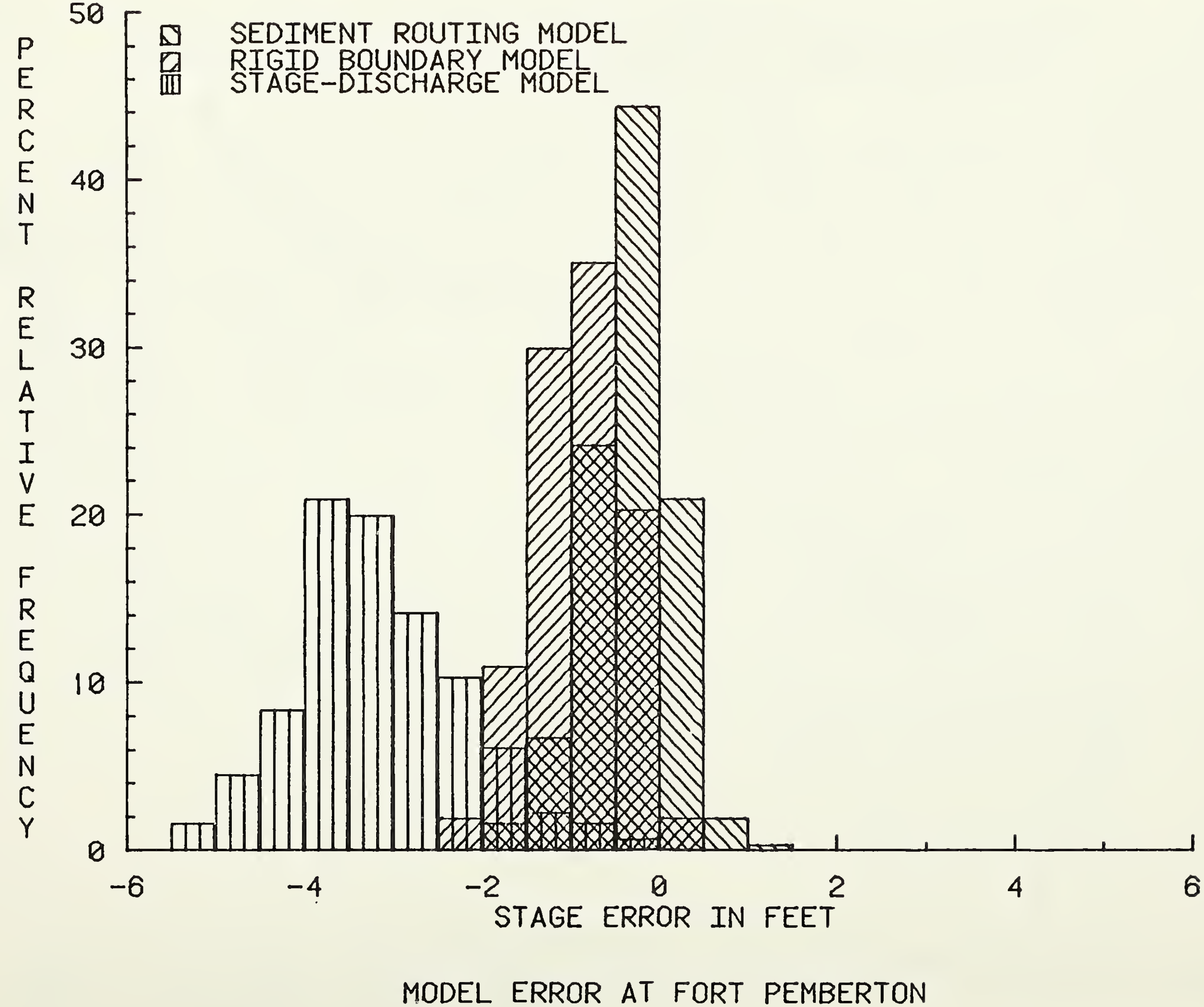


Figure 13. Model error frequency at Fort Pemberton.

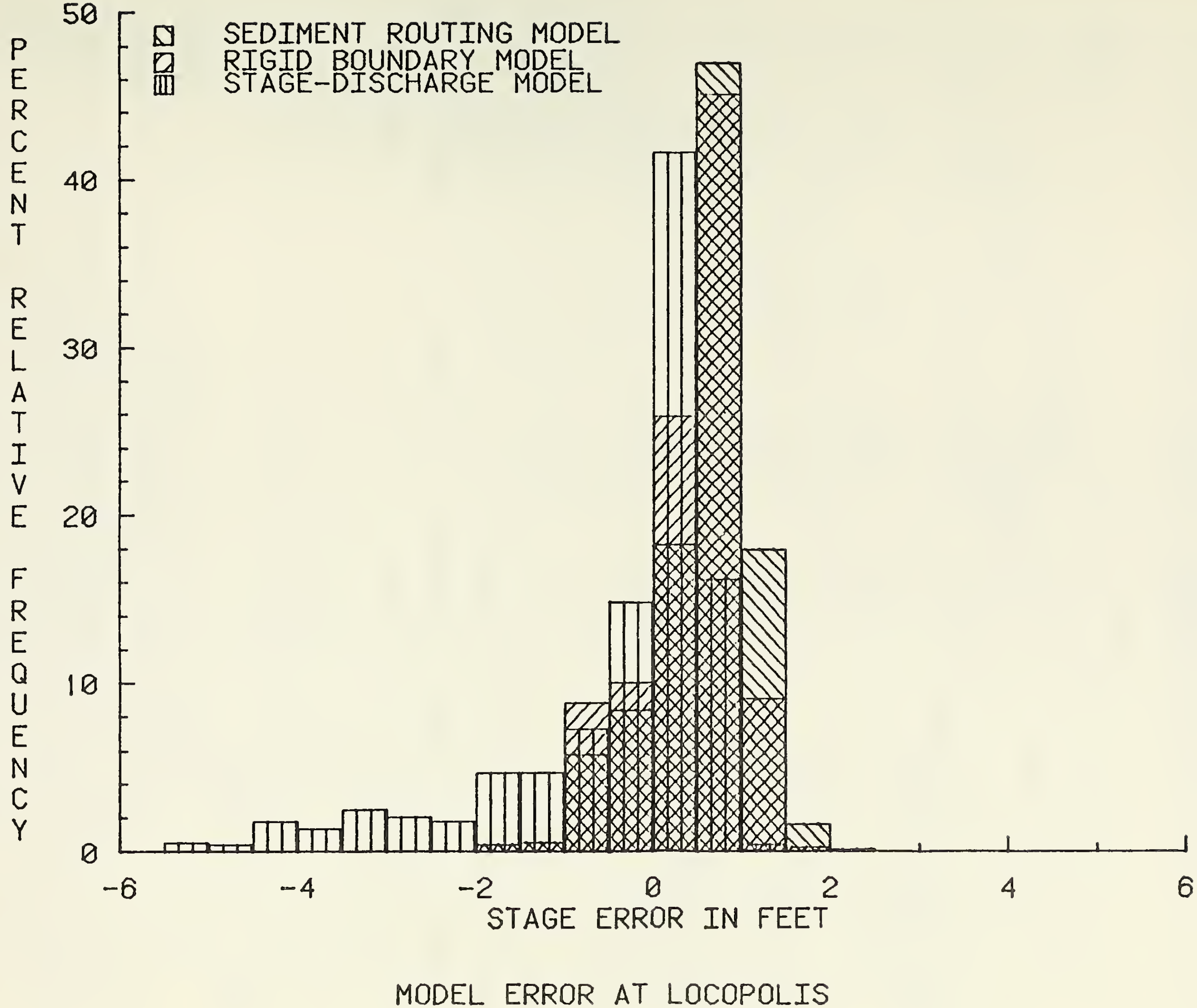


Figure 14. Model error frequency at Locopolis.

error for each model, and Table 2 lists the statistics of the absolute error for each method.

As indicated in the figures and table, all three methods have approximately the same mean error for Locopolis, but the process models have much lower maximum errors than the stage-discharge relationships.

Table 2. Statistics of absolute model errors.

	Error in Feet			
	Calibrated		Verification	
	Mean	Maximum	Mean	Maximum
Stage-Discharge Model				
Fort Pemberton	2.56	10.38	3.47	7.27
Locopolis	0.33	2.56	0.80	5.48
Rigid Boundary Model				
Fort Pemberton	0.90	3.97	0.92	2.39
Locopolis	0.29	2.27	0.62	1.91
Sediment Routing Model				
Fort Pemberton	0.88	3.60	0.45	1.78
Locopolis	0.34	2.12	0.74	2.21

Since there are few channel changes in this reach, the results of the two process models, rigid boundary and movable bed, are essentially the same. At Fort Pemberton the sediment routing model is clearly better than the simple backwater model, assuming a rigid boundary bed, and is superior to the statistical approach because the sediment routing model predicts and adapts to changes in river conditions related to sediment movement and deposition. The stage-discharge and rigid boundary models, however, are based only upon limited historical conditions and cannot adapt to a changing environment.

Statistical prediction of river stage, though easy to apply, should be limited to stable rivers where there are adequate data over the range of flow conditions. The backwater model with rigid boundary assumption should be limited to stable reaches where little change in cross-sectional data occurs. However, since it can account for varying flow conditions, it can be used only where limited stage and discharge data are available. The sediment routing computer model that considers the physical significance of open channel flow and fluvial geomorphology and that computes

changes in a river environment is the only feasible approach to predict the response of a river to man's activity, such as implementing a river cutoff, dredging or floodplain encroachment.

USE OF PHYSICAL PROCESS SIMULATION MODEL IN EVALUATING DATA MONITORING SYSTEM

General

Data is the key element for describing and studying the watershed response. Accurate and adequate data sets are required for documenting and describing the correct system response and for model development, calibration, verification, sensitivity analysis, and application. Unfortunately, many existing data sets are neither accurate or adequate for a detailed system analysis. A problem often occurs when a data collection network has been improperly designed and operated thus providing inaccurate and inadequate information that is neither spatial nor temporally consistent. Many times poor data sets are not discovered until considerable time and effort has been spent in their collection. It is important that a clearly defined methodology be developed for evaluating data monitoring and collection programs to identify existing or potential problems in the existing or proposed data collection networks.

Available data are often not enough to describe spatial and temporal variations of the system. Application of physical process simulation models calibrated with limited data to generate the spatial and temporal variations is the only feasible way to examine the temporal and spatial needs of data.

A systematic approach for evaluating and/or designing a data collection system considering spatial and temporal variations is proposed. The adequacy of a spatial and temporal design is dependent on the purpose of the study, the spatial and temporal variability of a physical environment, the desired accuracy of analysis, and the availability of personnel and financial resources. The recommended approach includes identification of the problem, survey and evaluation of the current data base, and application of available models to determine the sensitivity of data and to evaluate the adequacy of spatial and temporal requirement of specific data. The approach has been applied to the data collection program at the Four-Mile Creek Watershed, Iowa. This watershed is maintained by Iowa State University under the sponsorship of the Environmental Protection Agency.

Approach of Application

Data Needs: This application presents a systematic approach to designing or evaluating a data collection system. The first task is identification of data needs. These needs are directed towards monitoring system response or towards development of a data base for applying mathematical models. In this study, the adequacy and completeness of the data collection network is assessed relative to mathematical modeling of the system being measured. In turn, a selected mathematical model is used to demonstrate help in evaluation techniques. Data needs are categorized and information delineated under each category. Needs are compared with available information in order to identify and assess any gaps that limit applicability of the data base.

Spatial and Temporal Designs: Spatial and temporal designs of a data collection network are important items to be delineated. Spatial design covers the location, number, and spacing of measurement points. Temporal design assesses sampling frequency and instrument timing of specific data. Adequacy of spatial and temporal design is dependent on the purpose of the study, spatial and temporal variability of a physical environment, and desired accuracy of analysis. A systematic approach to this problem was developed. This approach includes a survey and evaluation of the current data base, application of selected mathematical models to determine the model sensitivity to date, and an evaluation of the adequacy of spatial and temporal requirement of specific data. Spatial and temporal design of the collection network can be determined through statistical analysis of autocorrelation and space correlation. If a realistic value is set for the correlation coefficient for spatial and temporal data, measurement site spacing and sampling interval requirements can be determined. Mathematical models aid spatial and temporal assessment by depicting the watershed in terms of response timing and magnitude at various locations. These responses help in selection of instrument timing and size of measurement devices. If no data or inadequate data is available, the data base for the study area or from nearby sites can be used to provide realistic information about the site.

Quality of Data: Quantity is an insufficient measure of a data collection network. Data quality is another important consideration. The quality of data can be assessed by simple comparisons of timing between

sampling sites, by relative magnitude of measurements, by trends in the data, and by model sensitivity to good and bad data. Data quality must be considered in evaluation of a data collection network with respect to measurement techniques and instruments, accuracy of the model being used, and the size of the area being modeled.

Use of the Model in Data Evaluation

Time of Concentration Determination: The time of concentration is an important factor when designing a gaging system since it helps determine at what intervals readings should be taken by providing insight into the watershed's response to a given rainfall. Rainfalls of specified return periods are calculated using a regression developed from information in United States Weather Service Technical Paper No. 40 (Hershfield, 1961).

In order to reach a time of concentration, it is expedient to assume a constant rainfall excess. Since interest is in time it takes for the water to travel from the furthest point of the watershed to the outlet, the infiltration and interception for the time of concentration runs are set at zero. To account for infiltration and interception the actual rainfall rate is multiplied by a factor from 0.1 to 0.4 to account for losses. The 0.1 factor is used for the one-year storm and the 0.4 factor is used for the 100-year storm. The remaining storms with return periods between these two values are calculated by linearly interpolating between the one- and 100-year volumes according to the storm's actual volume.

The time of concentration for site 1 varies between 16 and 112 minutes and those for site 8 between 28 and 200 minutes depending on the storm's return period. An estimate of the time it takes the watershed to completely respond to a rainfall input is important. Depending on the number of intermediate points desired between the start of rainfall and the time of concentration an idea of the time interval and when discharge readings should be taken is provided.

Sensitivity Analysis: A sensitivity analysis is necessary for two reasons. The analysis is important in determining the quality of the various data needed in order to keep errors within certain limits. It is also a useful aid in the calibration process in that it gives the user an idea of how the simulated hydrographs respond to changes in the parameters being calibrated.

The sensitivity analysis is carried out on the medium sized watershed (ISU site 8) for two storms. The storms occurred on May 27, 1978 and August 15, 1977. These storms are used since they represent two distinct types of rainfalls that occur at the site: The first being of short duration, high intensity and the second of long duration, low intensity.

In the analysis, the parameters required as input to the model are varied one at a time at various percentages of their original values while leaving all other parameters constant. The results are graphed in Figures 15 and 16 for peak flow only. Volume and duration are similarly affected. The results show that the most sensitive parameters are the soil characteristics and the overland flow resistance which is governed by the percentage of ground cover and the resistance factor. This could be significant since these two areas have little data collected. However, the calibration process can fill in these gaps and still produce reasonable simulations as was noted earlier.

Correlation in Simulated Runs: To help assess the required spatial and temporal design for the water discharge gaging stations in the entire watershed, correlations to determine how the discharge varies in space and time were determined. The available discharge records along the main channel are such that they are inadequate in providing the data necessary to make such correlations on a basis any finer than hourly. Since most of the events are of less than a day in length, this information is vastly important. Thus, in order to provide information for such correlations, the runoff results from the 100-year storm for the entire watershed are substituted for actual data. These hydrographs are simulated for the downstream end of the watershed (channel 1) and a point further upstream (channel 5). These points correspond to the USGS gaging station at Traer and Lincoln, respectively. An example of a hydrograph is given in Figure 17.

An autocorrelation is made for each hydrograph at both stations. The time between discharge samples is varied and determines how the discharge at different time intervals is correlated. This is done to help assess the time increment that would be most useful for taking readings. For example, if readings are taken at highly correlated time intervals, little information is gained by each and excessive data is taken. However, if the readings are recorded at intervals that have very little correlation,

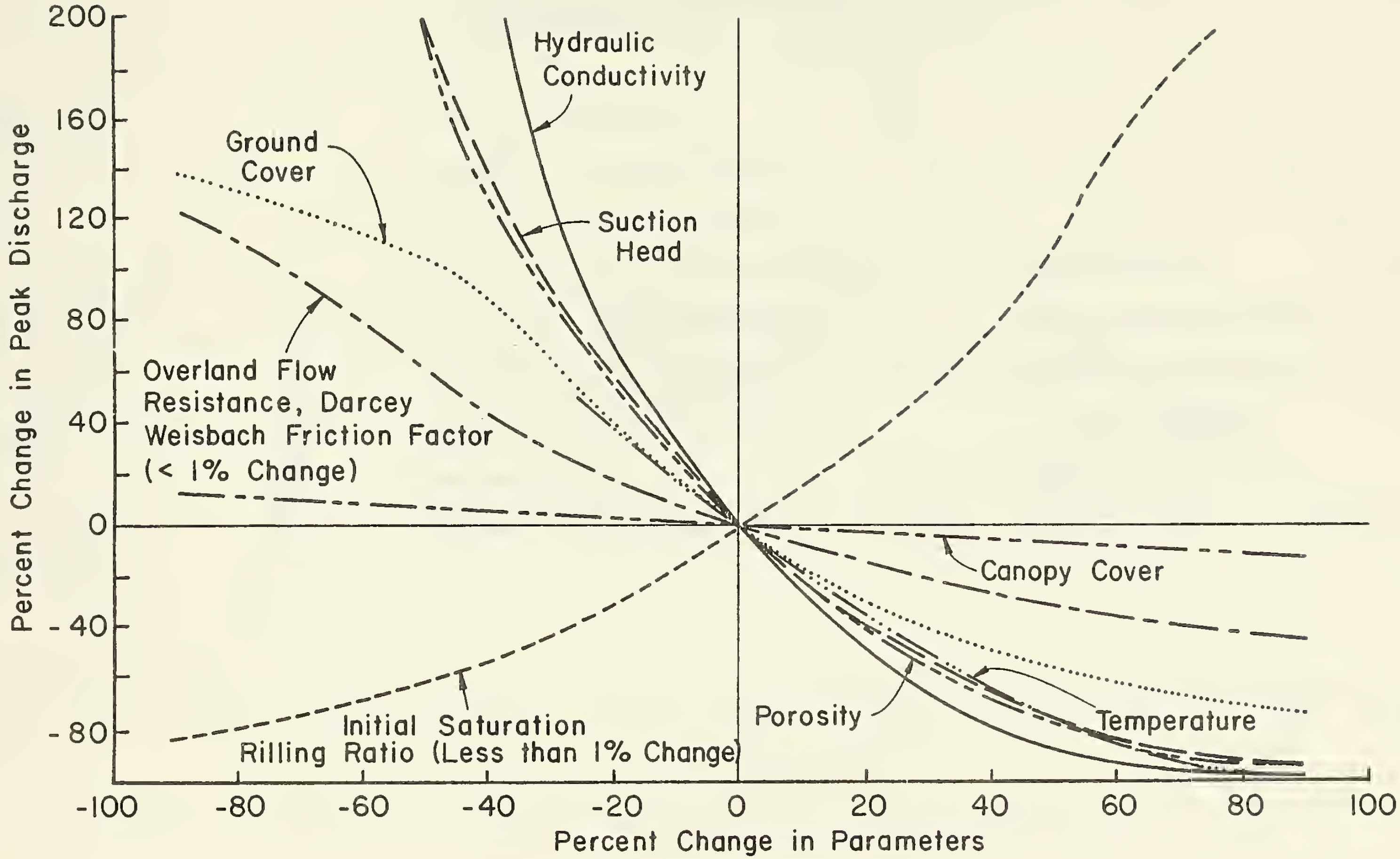


Figure 15. Peak discharge sensitivity analysis for watershed ISU9, storm of May 27, 1978.

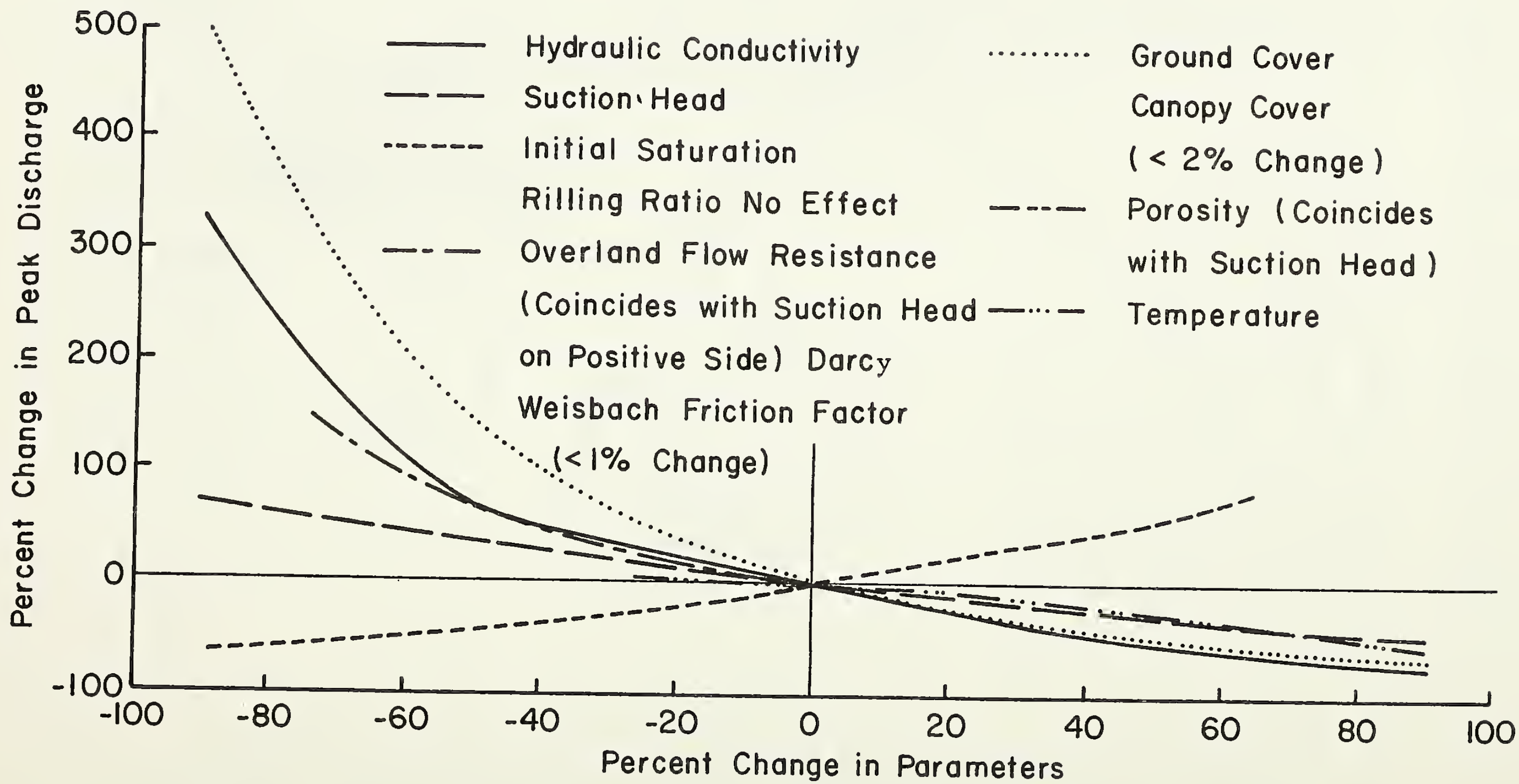


Figure 16. Peak discharge sensitivity analysis for watershed ISU8, storm of August 15, 1977.

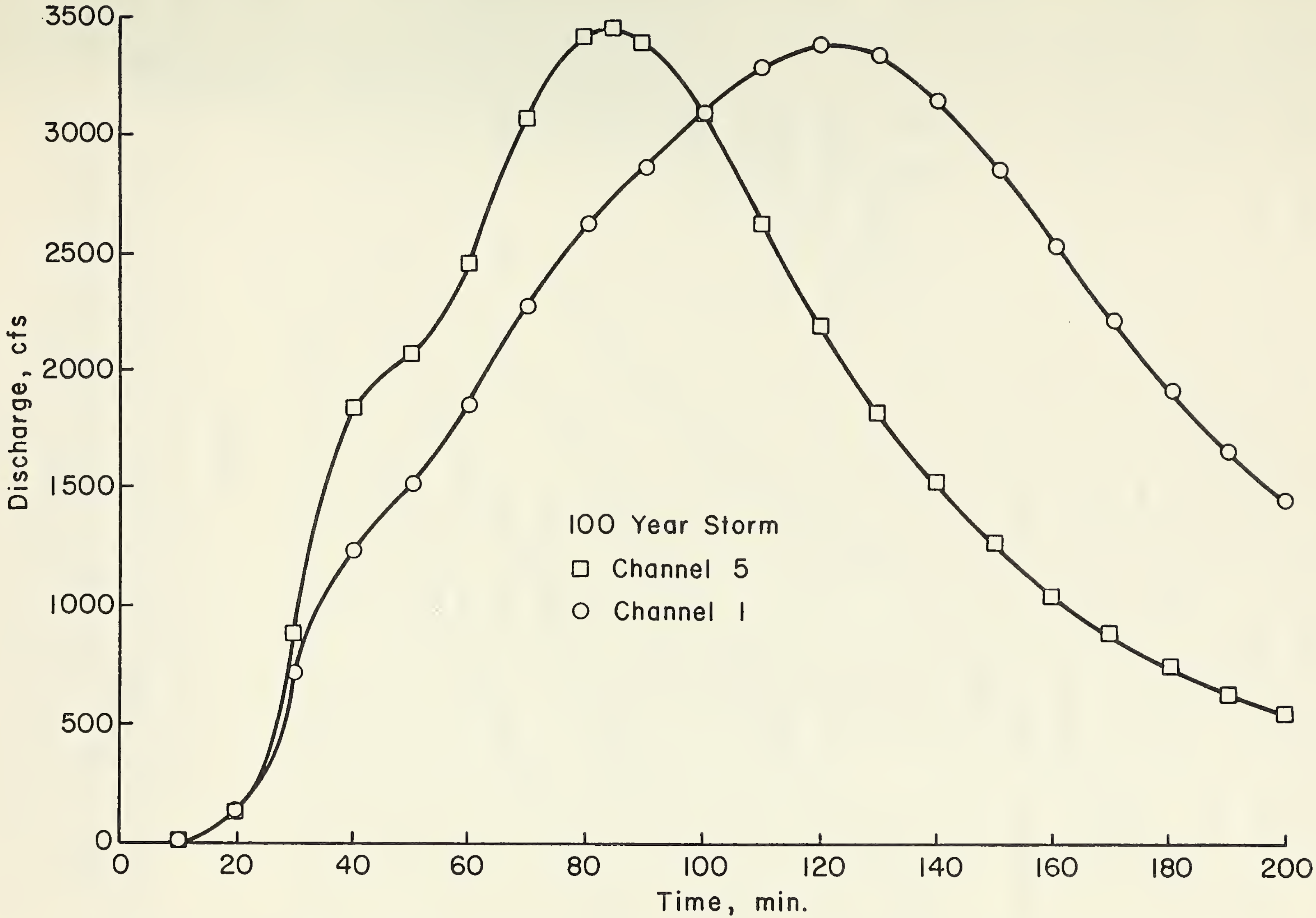


Figure 17. Simulated hydrographs for 30 minute, 100 year storm (Time is real time).

the data is too sparse and of little use. The results of the autocorrelation are given in Figure 18.

A log cross correlation was made between the gaging stations for each storm. The length of time between discharge samples at channel 1 and channel 5 is varied. This correlation helps with the spatial design. The spatial design can be evaluated by the extent of correlation existing between the stations for the various time lags in general. If the correlation is always high or if it is always low the stations are not spaced properly for the same reasons given in the preceding paragraph. The results are shown in Figure 19.

As stated previously there should be an upper and lower "correlation band" where sample timing and station spacing occurs. The upper correlation may be about 0.8. The lower correlation can be estimated using statistical techniques. The 30-minute storm is a good one to design the system with since this type of short duration high intensity storm causes high discharges which in turn result in large sediment and non-point pollutant yield. This will result in extra data being taken for longer storms, but it would not be wise to design the system for longer storms and then collect poor data for short storms. The system should be designed with more correlation than the lower limit calculated so that bad data can be identified using nearby stations or data gaps filled in atstation malfunctions.

Use of physical process models can aid in the design and analysis of data collection systems. Process models can be used as a basis for identifying data gaps and checking data quality. They can also be used to simulate data that can be utilized in correlation analyses and design modification. Use of models in this fashion allows a more efficient, better conceived collection network.

SUMMARY

This paper presents a brief overview of various watershed modeling efforts at Colorado State University. All of the developed models are based on physical significance that considers the principles of conservation of mass, momentum and energy. Different levels of models have been developed for practical application.

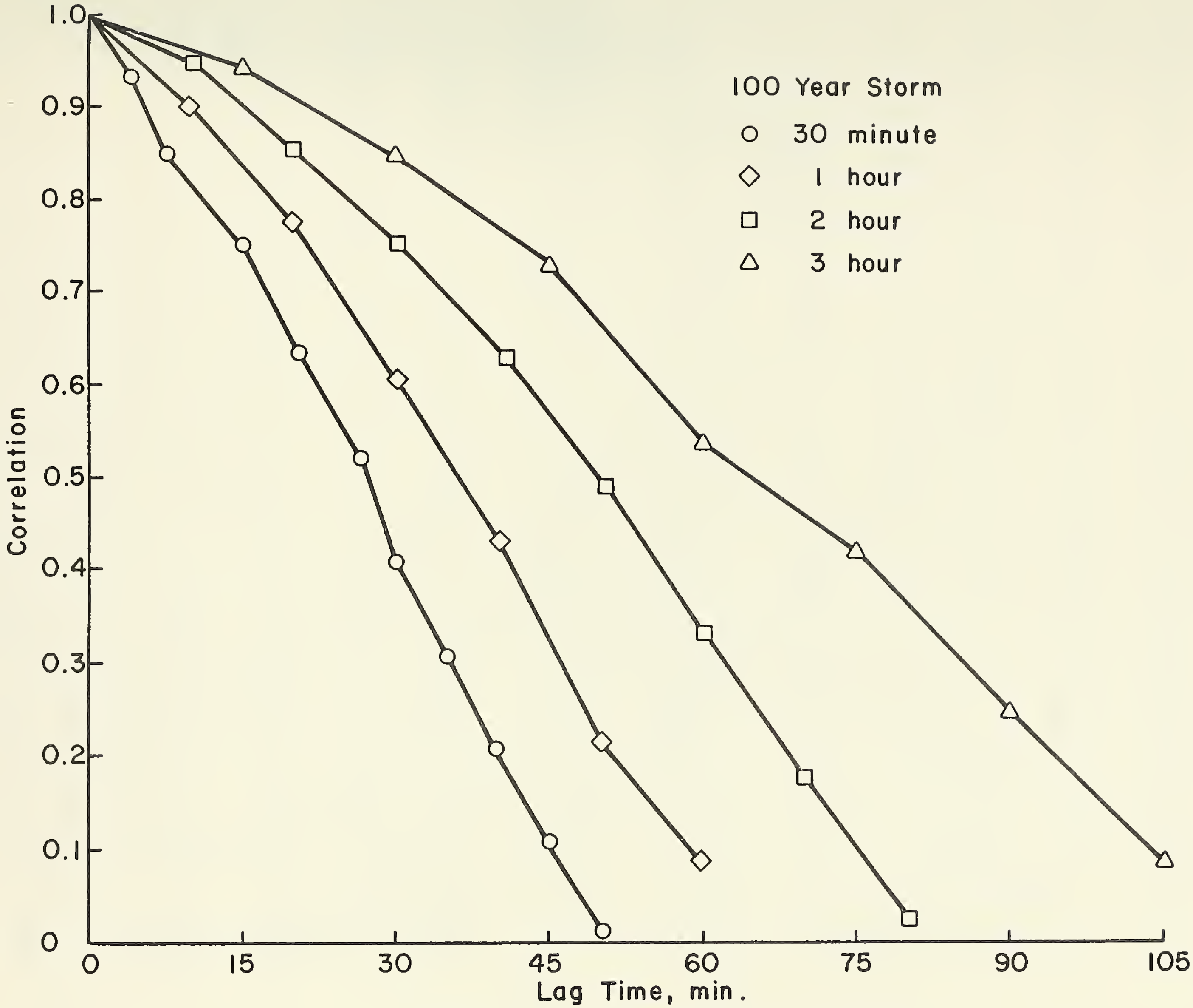


Figure 18. Autocorrelation for channel 1.

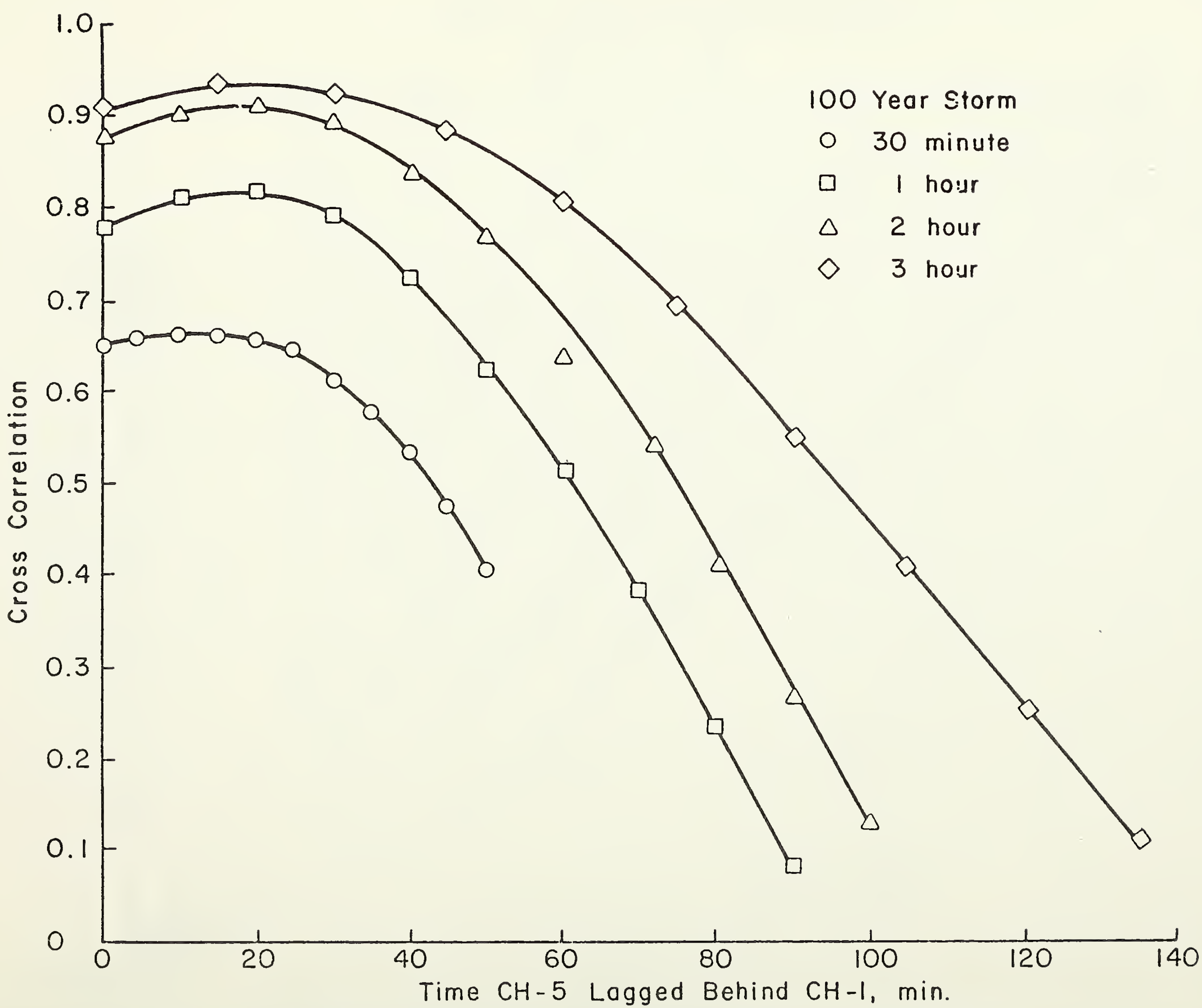


Figure 19. Cross-correlation of simulated hydrographs.

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IOWA WATERSHED MODEL

by
Thomas E. Croley II, Subhash C. Jain
and Gene Whelan*

Due to Federal legislation, i.e. PL 92-500 and amendments, watershed modeling has become increasingly important. Evaluation of physical and economic development, management, and watershed use is necessary. Due to their flexibility, watershed models can encompass a wide range of physical and economic variability. This includes catchment variability with respect to rainfall, soil type, land-use, topography, channel description, and related parameters. The model describes the catchment in fine detail by retaining individual characteristics throughout the watershed and includes overland and channel models of water and sediment.

Watershed Representation

The entire catchment is divided into subcatchments about all tributaries of concern and each subcatchment is further divided into a number of sections along lines of steepest slope as the side boundaries. Each section is treated as a "streamtube" so that neither runoff nor sediment transport is considered across the side boundaries of the section (Figure 1). The watershed characteristics vary along the streamtubes. Each streamtube is further divided into a number of segments according to the contours (slope) of the streamtube. Each segment is represented by a characteristic rectangular element and has a number of watershed characteristics associated with it. These consist of slope, characteristic length and width, land-use and soil characteristics, rainfall data (intensities, durations, etc.), and roughness coefficients.

Overland flow and sediment flow enter the streamtube at the midpoint of the lower streamtube boundary, called a "node". If the distance is small between nodes, this concept can be a very good approximation to the lateral inflow into a stream (Figure 2). Overland and channel (flood and sediment) routing is performed from node to node via natural channel shapes and, mathematically, routing is performed via numerical techniques on the computer. A special node numbering and coding scheme has been developed to route the flow in a fast, efficient manner.

Advantages and Disadvantages

The advantages of the watershed representation are that arbitrarily fine definition can be given to any watershed where the surface is complex. This enables closer approximation to variable slope, roughness, infiltration, soil types, land-uses and rainfall. Segments of the watershed can be easily changed, thereby allowing studies of land treatment effects, land-use options, cropping practices, construction practices, channel redesign and/or variability. Since each segment retains its own characteristics, rainfall can be spacially approximated as it nearly exists. Calculation of flood and sediment hydrographs allows calculation of sediment production, transport and deposition along streamtubes. The model uses readily available data from the different agencies which allows relative ease in conversion from watershed to watershed. Since the program is written in Fortran IV-G, Fortran WATFIV and CDC conversions are quite simple (since all are based on Fortran).

*Institute for Hydraulic Research, University of Iowa

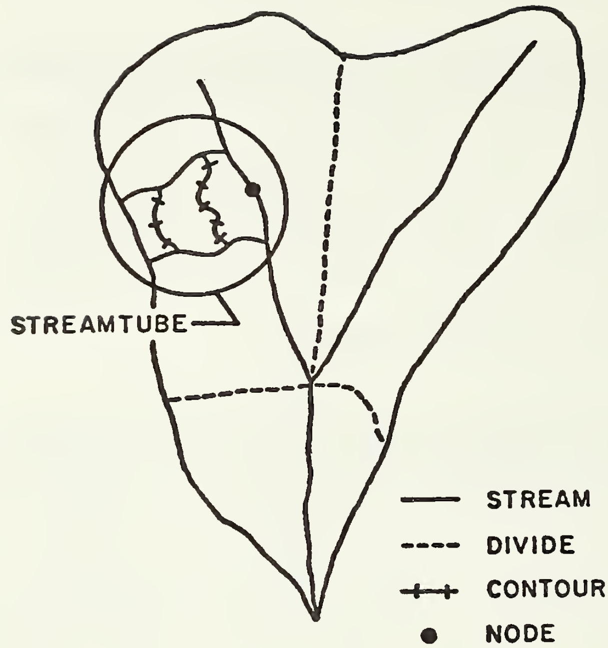


Figure 1. Natural Watershed and Streamtube Representation

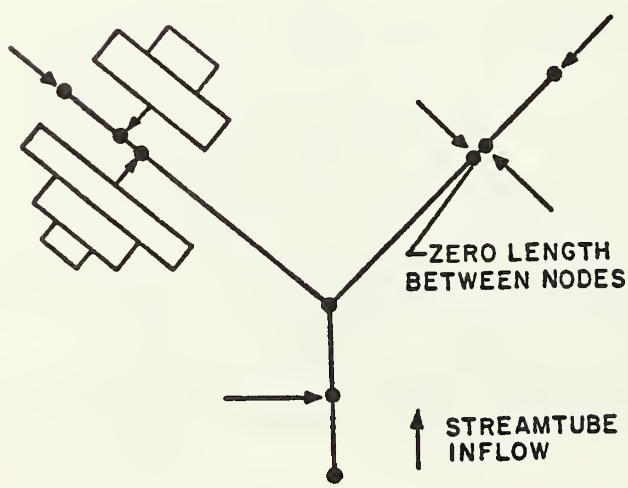


Figure 2. Characterization of Watershed, Streamtubes, Nodes, and Zero Length between Nodes

The disadvantage also lies in the extensive data requirements and the techniques to obtain them. While most data is obtained from topographic, land-use, and soil maps, the remaining data is extracted from various measurements of the streamtube segments, which, depending upon the degree of definition of the watershed, may be quite large (see Appendix). An example compilation, consisting of 300 nodes (about 700 streamtube segments), may take one man-month. Organization of the data is also time consuming. The data is grouped according to their nodes, but special care must be taken to ensure it is correct. Finally, the model does not take into account scour or deposition in channel ways.

Conclusion

The model is being designed to perform most of the calculations for the user. All that is required is the raw data in the correct sequence. Almost any watershed configuration can be handled. This model is currently being tested on a rural watershed with minor urban development. A few features of the model include: rainfall varying spacially and temporally, flood and sediment hydrographs printed upon request at any location on the watershed, cross-sections automatically calculated, natural channel shapes and geometric shapes can be used, different roughness coefficients corresponding to different depths of flow in the channel can be handled, more than one storm can be simulated on the watershed at different locations at different times. Eventually the model will be combined within an interactive digitizing, editing and mapping structure.

Appendix

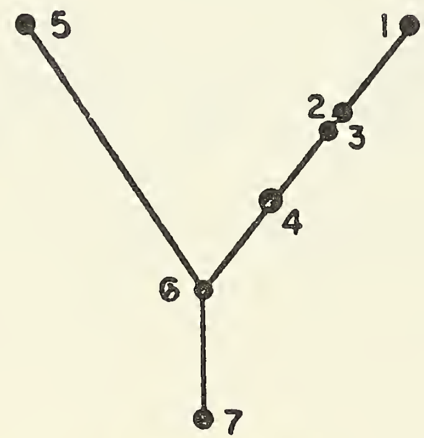
Data required for computer model and where this data might be obtained

INPUT	FROM WHERE
Numerical Analysis Data	
Time increment on streamtube	Engineering Judgement (300 sec)[1]
Time increment on channel	Engineering Judgement (60 sec)[1]
Cut-off limit for streamtube	Engineering Judgement (.01 cfs)[1]
Minimum time increment for channel	Engineering Judgement (30 sec)[1]
Watershed Representation	
Number of nodes	Watershed Division Map (Topographic map)
Node numbers and corresponding node codes	Watershed Division Map
Conversion constants	Depends upon units used
Number of raingages Storm lengths Storm starting times Rainfall excess data varying temporally	NOAA, US Weather Bureau State, county, local governments, etc.
Streamtube Segment Data	
Length	Topographic Map
Width	Topographic Map
Manning's roughness coefficient	CSU paper 93, Crawford and Linsley
Slope	Topographic Map
Power exponent in uniform flow equation	Engineering Judgement (~ 2)[1]
Pertinent raingage	(see above)
Soil and Universal Soil Loss Equation Parameters	
Weighting factor	Engineering Judgement (1.0)[1]
Soil erodibility factor (K)	SCS
Cropping factor (C)	SCS
Sediment shear stress exponent	Engineering Judgement (3/2)[1]
Sediment coefficients: C_t	Calibration
C_d	Calibration
Circular Channel	
Radius Slope Manning's roughness coefficient Length of channel	Topographic Map, field work, or an agency
Non-Circular Channel	
Slope	Topographic Map
Three Manning roughness values Depths corresponding to Manning's roughness	Engineering Judgement, USGS or other agency
Gage elevation-distance for cross-sections	Topographic Map
Length of channel	Topographic Map
Data Indirectly Required	
Land-use of watershed	Aerial photographs, SCS, USGS

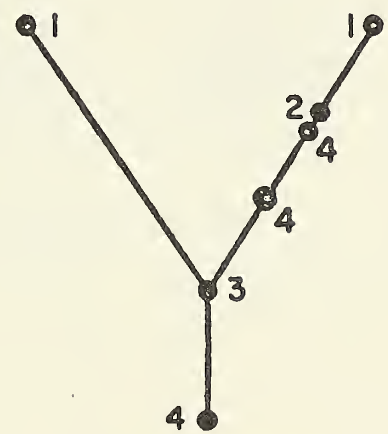
[1] Values found pertinent to the model through literature or by working with the model

Table 1. Overland Watershed Data

Node Number	Node Code	Streamtube Segment Number	Length (Feet)	Width (Feet)	Area (Sq.Feet)	Manning's Roughness Coefficient	Slope	Rain Gage Number	K Soil Erodibility Factor	C,P, or T Land Use Code	C_c Cropland Factor
1	1	a	178	1404	249,912	.15	.0800	1	.37	T	.003
		b	321	324	104,004	.15	.1091	1	.37	T	.003
2	2	a	136	389	39,304	.2	.1111	2	.37	T	.003
		b	145	562	81,490	.2	.0325	3	.37	T	.003
		c	215	435	93,525	.15	.0621	1	.37	T	.003
3	4										
4	4										
5	1	a	130	280	36,400	.2	.1108	2	.35	P	.001
		b	148	568	84,064	.15	.0525	3	.35	P	.001
6	3										
7	4										



NODE NUMBERS



NODE CODING

Table 2. Channel Cross-Sectional Data

Node Number	Length (Feet)	Depth D_1(ft)	Manning's Roughness Coefficient n_1	Depth D_2(ft)	Manning's Roughness Coefficient n_2	Slope	Manning's Roughness Coefficient n_3	$\text{Distance}_j/\text{Elevation}_j$ (j=1,p) (ft)/(ft)
1	535	3.5	.05	5.5	.05	.032	.045	0/736, 8/734, 17/732, 25/730, 33/728, 40/726, 49/725, 55/726, 63/728, 75/730 82/732, 86/734, 92/736
2	200	3.5	.05	5.5	.05	.012	.045	0/734, 10/732, 15/730, 75/728, 80/726, 100/724, 125/726, 133/728, 138/730, 150/732, 158/734
3	100	2	.01			.021		(Circular Pipe Culvert)
4	125	3.0	.06	5.0	.06	.018	.05	0/732, 36/730, 38/728, 45/726, 50/724, 56/726, 58/728, 63/730, 78/732
5	338	4.0	.045	6.0	.05	.009	.045	0/732, 31/730, 45/728, 49/726, 78/723. 90/726, 93/728, 101/730, 130/732
6	128	3.2	.05	4.5	.06	.008	.05	0/730, 18/728, 24/726, 28/724, 80/723, 95/724, 101/726, 122/728, 136/730

ECONOMICS AND THE ENVIRONMENT: IMPACTS OF EROSION RESTRAINTS ON CROP PRODUCTION IN THE IOWA RIVER BASIN

Klaus Alt[1] and Earl O. Heady[2]

I. INTRODUCTION

This study simulates the effects of various strategies to control excess erosion and sedimentation from field crop production in a watershed of the Iowa River in East-Central Iowa. These effects are simulated with the aid of a linear programming model.

Complicated environmental processes, such as erosion, do not lend themselves to easy simulation. The physical variables involved are so numerous and their interactions so intricate that a perfect quantification may be unattainable at present. This study examines the interactions using some of the currently available methods.

Erosion represents an undesirable side effect of soil tillage, namely the movement of soil particles from their site of origin by water or wind. The term "gross erosion" refers to the movement of soil for any distance, no matter how short. However, if all soil that moves is deposited within the crop field of origin, there would be no pollution problem because no off-site damage would be incurred. The delivery of

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[1]Klaus Alt is an Agricultural Economist, Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture

[2]Earl O. Heady is a Distinguished Professor of Agriculture, Department of Economics, Iowa State University, and Director, Center for Agricultural and Rural Development, Iowa State University.

eroding soil to off-site waterways (where it becomes sediment) is termed "sediment delivery."[3]

Sediment is a pollutant which "occupies space in reservoirs, lakes, and ponds; restricts stream and drainageways; reduces crop yields in a given year; alters aquatic life in streams; reduces the recreational and consumptive use value of water through turbidity; and increases water treatment costs. Sediment also carries other water pollutants such as plant nutrients, chemicals, radioactive materials, and pathogens" (Johnson and Moldenhauer, 1970; p. 3).

Erosion is a major pollution problem in Iowa. The Iowa Water Quality Report states that soil erosion in Iowa in 1974 was at the highest level in 25 years, with 4.5 million acres having gross erosion of more than 10 tons per acre (Iowa Department of Environmental Quality, 1975). Gross erosion of 40 to 50 tons per acre was not uncommon and reached levels as high as 200 tons per acre in some areas.

The pollution problem in the Iowa River attributable to sediment is unusually high for eastern Iowa. "Suspended sediment concentrations found in the Iowa River have ranged from nine to 4,700 mg/l in recent years. The annual computed sediment load to Coralville[4] was 1.34 million tons in 1966. This value represents over 475 tons of sediment per square mile of drainage area" (Iowa Department of Environmental Quality, 1975; p. II-79). Although this represents less than one ton of sediment delivered per acre, the average amount of gross erosion is about 3.7 tons

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[3] Although this delivery could be referred to as "net erosion," that term is not used.

[4] The Coralville Reservoir forms the downstream termination point of the study area.

per acre,[5] assuming an average 20 percent sediment delivery ratio. Of the rivers in Iowa, only those in western Iowa, particularly those which have been channelized and straightened, have sediment loads in excess of the Iowa River above the Coralville Reservoir (Iowa Department of Environmental Quality, 1975).

The sediment load which is deposited in the Coralville Reservoir has attracted widespread public attention. The 5,000 acre lake is a valuable recreation source, and continued enjoyment of this resource may be curtailed if sediment continues to accumulate at present rates. This study will identify and quantify the economic effects of attempts to reduce the sediment contribution from agricultural land use.

Objectives and Procedures

This study has two major objectives. The first is to improve the application of analytical techniques in the study of impacts of environmental policies upon agriculture. The second is to identify and quantify the effects of various policies designed to increase sediment pollution abatement where negative externalities result from the individual decisions of farmers in a particular area of Iowa. The effects include changes in production costs and methods, farming practices, and land use, as well as environmental quality.

The study first estimates the situation which prevails in the absence of environmental controls. Throughout the discussion, this solution will be termed the "baseline solution." Several environmental policies are

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[5] This average figure includes all land in the drainage area including permanent pastures and forests. The average figure for the tilled acres may be expected to be higher.

then simulated. The first of these is an absolute limit on gross erosion per acre cropped. This limit is specified at three levels ranging from 10 to 3 tons/acre/year. Another policy treats the study area as a single planning unit upon which a maximum limit on sediment delivered to the Coralville Reservoir is imposed. A limit on the amount of sediment delivered simulates the effect of a water quality standard imposed upon the study area as a whole because water quality and sediment delivery are directly related. A third policy alternative assumes payment of subsidies to farmers for construction of terraces and for row crop tillage conforming to the soil slope contours. Subsidies previously have been paid to farmers to help defray the cost of certain erosion-reducing measures, including terracing. The Iowa Soil Conservancy Law implies that these subsidies will continue (e.g. it states that no landowner can be required to establish particular soil conservation practices unless cost-sharing funds of at least 75 percent of the establishment costs have been made available).

II. SOILS IN THE STUDY AREA AND EROSION

The study area is located in East-Central Iowa along the Iowa River and includes all of the watersheds of the Iowa River between the Marshalltown River gauge and the dam at the Coralville Reservoir. The land area totals 938,050 acres or about 1,466 square miles. It covers slightly less than half of the total area of 3,115 square miles which drains into the Coralville Reservoir.

A large percentage of the land area is tilled for agricultural crops (Table 1). The predominant crops are corn and soybeans. Lesser acreages are planted to oats, required, in part, as a cover crop for the hay seedings. The cropland not planted to either row crops or oats produces hay, primarily alfalfa. The rather large acreage of "other cropland" is explained below. The land not suitable for tillage supports permanent pasture and a small amount of forests; the latter occurs typically on rough land next to riverbanks and gullies.

Table 1. Major land uses of study area in 1967

Crop	Acres[a]	Percent of Total
Corn	310,293	33.1
Soybeans	98,166	10.5
Oats	76,805	8.2
Hay (cropland)	90,109	9.6
Cropland pastured	71,523	7.6
Other cropland	114,694	12.2
Permanent pasture	92,411	9.8
Forests	58,091	6.2
Other	25,959	2.8

[a]Source: (Rosenberry, Padgitt, and Prophet, 1973).

Table 2 identifies the soil aggregations of this study. These soil aggregations are chosen on the basis of comparable soil management and environmental characteristics, such as slope, drainage, and texture as well as crop yields. The cropland acreages of each soil aggregation are used in the study as restraints on the tillable acreages, with one exception. Soil aggregation D is listed as having a cropland acreage of 63,115 acres, all classified in the "other cropland" category (Rosenberry, Padgitt, and Prophet, 1973). This soil aggregation includes areas of stony riverwash,

Table 2. Soil aggregations used in study

Soil Aggregation ID	Soil Description Summary[a]	Land in Study Area[b]			
		Cropland Not Terraced	Cropland Terraced	Total Cropland	Total All Land Uses
A	Deep well drained upland soils; 5-14% slope; silt loam; Soil Resource Group (SRG) 3.	274,530	4,240	278,770	313,111
B	Deep well drained lacustrine and upland soils; 0-5% slope; silt loam; SRG 1 and 2.	220,470	3,324	223,794	248,245
C	Poorly drained bottomlands; 0-2% slope; silty clay loam; SRG 18.	114,831	0	114,831	148,408
D	Upland soils; 9-24% slope; silt loam; SRG 28 and 29. Not suitable for tillage because of shallowness or steepness or both.	(63,115)[c]	0	(63,115)[c]	107,450
E	Poorly drained upland and alluvial bottomland soils; 0-2% slope; silt loam to muck; SRG 10, 20, 22, and 23.	31,936	0	31,936	56,371
F	Well drained upland soils, 14-18% slope; silt loam; SRG 4.	31,824	637	32,461	42,363
G	Moderately well drained upland soils; 5-14% slope; loam to silt loam; SRG 6 and 12.	7,930	0	7,930	9,364
H	Somewhat poorly drained upland soils; 5-14% slope; loam; SRG 15.	5,767	0	5,767	8,174

Table 2 (continued)

Soil Aggregation ID	Soil Description Summary[a]	Land in Study Area[b]			
		Cropland Not Terraced	Cropland Terraced	Total Cropland	Total All Other Lands
I	Excessively drained upland soils; 0-14% slope; sand; SRG 13.	1,172	0	1,172	1,748
K	Shallow upland soils; 0-5% slope; loam to sandy loam; SRG 14 and 16.	1,813	0	1,813	2,811
Total		690,273	8,201	698,474	938,045

[a]The complete soil descriptions are given in (U.S. Department of Agriculture, Iowa Cedar Rivers Basin Field Advisory Committee, 1976).

[b]Source: (Rosenberry, Padgitt, and Prophet, 1973).

[c]Excluded from model. See explanation in text.

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shallow soils, and steep rocky hillsides with slopes in excess of 14 percent. It is assumed that this soil aggregation could possibly support permanent pasture, forest, or other nontilled land use, but that environmental and crop yield considerations would keep it from being tilled. Therefore, soil aggregation D is excluded from further consideration in this study.

Erosion

Erosion, a natural process, has helped to shape the earth's face. It has reduced rugged mountains to smooth hills and has cut channels for flow of surface water runoff to the oceans, often creating picturesque sights, such as the Grand Canyon, in the process. The beginnings of civilization were aided by the yearly floodings and deposition of streamborne sediment on the floodplains of rivers (e.g., the Nile, Euphrates, and Yellow rivers). This deposition fertilized the soils, a process which allowed the establishment of sedentary agriculture and induced the development of social systems capable of dealing with the resulting population concentrations. In modern agriculture, however, these erosion processes are no longer desirable because they result in net negative effects on the surrounding environment, both on-site and off-site. On-site effects include the eventual loss of productive topsoil and a lowering of crop yields. Other on-site effects relate to changes in farmability due to the creation of gullies or other erosion-induced land changes.

Off-site impacts include all effects of sediment in the waterways. Biological activity in water depends upon the presence of sunlight, which

can be excluded if the water is clouded with suspended sediment. Consequently, the ability of the water system to produce fish for commercial or recreational harvest may be impaired by high sediment concentrations. Sediment also has downstream effects. The sediment load in a waterflow can be deposited at any point where the speed of flow is reduced. A prime example is the progressive siltation of lakes and reservoirs, leading to an eventual complete filling of lakes and reservoirs with silt. In instances where a shipping lane is closed by sediment deposition, dredging costs also are incurred. Other indirect costs are caused by a raising of the streambed by deposited sediment, such as more frequent flooding and larger stream channels.

Although elimination of sediment carried in water may seem desirable, this possibility is precluded by nature's forces. Erosion occurs on all parcels of land. The erosion on construction sites and mining areas can be an important contributor to sediment loads in specific areas. Sediment also is produced by stream bank erosion and caving-in of bank overhang. Bank erosion is a significant factor in sedimentation of the Coralville Reservoir, because the Iowa River above Coralville meanders widely. However, the present study examines only the contribution of agricultural land to sediment production.

Estimation of sediment generated by various agricultural production methods involves two distinct questions: First, what amount of soil is moved within the field, i.e., the gross erosion; and second, what percentage of the gross erosion is actually deposited into the waterways, i.e., the sediment delivery ratio. The estimation of gross erosion and sediment delivery is detailed in the following discussion.

Gross erosion

The generally accepted estimation method for gross erosion uses the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965). This equation was developed by many scientists over a period spanning many years. The function was designed specifically to relate the effects of various crop growing practices to the resulting gross erosion. The USLE is not generally used to estimate erosion from nonagricultural sources (highway and building construction or urban sources). Therefore, consideration throughout the remainder of this study will be restricted to erosion and sediment from agricultural sources.

The USLE predicts the amount of soil which is moved within the field by the force of rainfall striking the soil and by the surface water runoff. Much of this soil is redeposited in grassed areas or on flatter ground and does not actually leave the field. The soil loss equation has the form:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where A is the average soil loss, in tons per acre, per year.

"R is the rainfall and runoff erosivity index.

K the soil erodibility factor, is the average soil loss in tons per acre per unit of R, for a given soil on a "unit plot" which is defined as 72.6 feet long, with 9 percent slope, continuously fallowed, and tilled parallel to the land slope.

L the slope-length factor, is the ratio of soil loss from a given length of slope to that from a 72.6 foot length with all other conditions identical.

S the slope-steepness factor, is the ratio of soil loss from a given percent-slope to that from a 9 percent slope with all other conditions identical.

C the cover and management factor, is the ratio of the soil loss with specified cover and agronomic practices to that from the fallow condition on which factor K is evaluated.

P the practice factor, is the ratio of soil loss with supporting practices such as contouring or strip cropping to that with straight-row farming up and down the slope" (Wischmeier, 1976a; p. 35).

The soils with slopes of less than 2 percent were assumed to have no measurable soil loss. A slope of 1 percent designates essentially flat land, and the length of the "slope" is practically undefined. The C factor was computed for each rotation and tillage practice from data specific to Iowa (USDA, Soil Conservation Service, 1969). Using the provided factor values, an estimate of the gross erosion specific to each crop production activity of the model was computed with the Universal Soil Loss Equation. The computations were made separately for each soil component of each soil aggregation; only the resulting soil loss estimates were averaged to arrive at a weighted average for each production activity by soil aggregation. This method is preferable because averaging the USLE coefficients for the soils in each soil aggregate and computing the soil loss from average coefficients would lead to an erroneous estimation of soil loss.

Sediment delivery ratio

The USLE computations yield the gross erosion from sheet and rill erosion specific to each crop production activity. These erosion estimates are summed for the activity levels of the production activities which enter each model solution to estimate the gross erosion for each soil aggregation and for the whole study area. This total amount does not equal the amount of sediment delivered to the Coralville Reservoir.

> To compute the sediment yield in the drainage area, this estimate (of total erosion) must be reduced to compensate for deposition at the toe of field slopes, in field boundaries, in depressions, in constructed sediment basins and traps, and along the path traveled by the runoff as it moves from the field to a stream. Sediment additions from sources along this path must also be taken into account. The gross soil loss estimated by the equation should be used together with a deposition equation and estimates of sediment additions from gully, stream bank, and channel erosion. No deposition equation is now available, and a sediment delivery ratio is used as a lumped accounting for sediment load changes below the areas for which gross soil loss is computed. A sediment yield estimate obtained by this procedure is a long-time average for the particular watershed conditions (Wischmeier, 1976b; p. 7).

It may be assumed that such sediment delivery ratios are related to the size of the drainage area. It has been found that, despite wide variation in topographical and other influencing factors, the sediment delivery ratio may be specified to vary inversely as the 0.2 power of the size of the drainage area (Renfro, 1975). Clearly, such an estimation process forecasts the amount of sediment delivered to the mouth of the watershed. Wischmeier (1976a) argues that these types of estimates are confounded by stream bank erosion and sediment accretions from nonagricultural sources and cannot provide estimates of the contribution

of nonpoint cropland sources to water pollution. If the sediment delivery ratio is to be used for such estimates, it should be defined as "the ratio of sediment delivered at the place where the runoff water enters a continuous stream system to the gross erosion from the drainage area above that point" (Wischmeier, 1976a, p. 51).

The sediment-delivery ratios (Table 3) were developed on the basis of Wischmeier's more restrictive definition in view of the topography in each watershed.[6] The three watersheds containing the direct tributaries have significantly lower delivery ratios than would be expected on the basis of their sizes alone, but they contain most of the flat bottomland acreages. On these areas, the overland flow would be less likely to deliver sediment to the stream system than in the more hilly watersheds. The sediment delivery ratios used in the model for each soil aggregation are computed as the average of the watershed delivery ratios weighted by the occurrence of each soil aggregation within each watershed.

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[6]The sediment delivery ratio estimates were developed by Ed Burr, Iowa State Geologist, and Bob Boyce, Geologist, Central Technical Unit, both Soil Conservation Service, U.S. Department of Agriculture. The estimates were tested and refined with a sediment routing model as described by Boyce (1975).

Table 3. Watersheds in the study area

Code	Stream name	Drainage area[a] Sq. miles	Acres	Sediment delivery ratio
12	Burnett Creek	32.4	20,740	18.0
13	Linn Creek	66.8	42,750	11.0
14	Timber Creek	124.0	79,360	10.0
15	Deer Creek	85.6	54,790	10.0
16	Sugar Creek	21.6	13,820	21.0
17[b]	Direct Tributaries, Marshalltown to Deer Creek	89.6	57,340	6.0
18	Richland Creek	60.3	38,590	16.0
19	Otter Creek	41.2	26,370	8.3
20	Salt Creek	223.0	142,720	4.0
21	Walnut Creek	91.3	58,430	12.0
22	Honey Creek	29.9	19,140	21.0
23	Bear Creek	222.0	142,080	7.0
24	Direct Tributaries, Deer Creek to Marengo above Bear Creek	142.3	91,070	3.6
25	Hilton Creek	21.5	13,760	22.0
26	Price Creek	30.9	19,780	12.0
27	Knapp Creek	30.6	19,580	15.0
28	Hoosier Creek	48.8	31,230	13.0
32[b]	Direct Tributaries, Marengo through Coralville Reservoir	189.2	121,090	5.0

[a]Source: (USDA, Iowa-Cedar Rivers Basin Field Advisory (Committee.)

[b]Only part of this watershed is included in the study area.

III. THE MODEL USED

A linear programming model is used in the analysis of the impact of environmental control measure applied to the study area. There are three components to a linear programming model: an objective function, the restraints which typically take the form of limited amounts of resources, and a large number of alternative combinations of these resources in production processes.

A linear programming model may be written in a general form as:

$$\text{maximize } Z = \sum_{j=1}^{n} c_j x_j$$

$$\text{subject to } \sum_{j=1}^{n} a_{ij} x_j \leq b_i$$

$$x_j \leq 0$$

where i = 1, 2...m.

In this specification, the c_j represents the objective function values for each of the n activities, and the x_j are their levels of activity. The a_{ij} represent the requirements of resource i per unit of activity j, while the b_i denote the resource availabilities of the m resources.

In the present model, the chosen objective is minimization of the monetary production costs of the required level of field crop production in the study area. The restraints include land availability, limits on cropping patterns due to agronomic considerations, minima on crop output expected from the study area, and alternative environmental restraints.

A large number of production alternatives are specified, differentiated by such characteristics as tillage methods, soil conservation methods, and crop rotations. The production alternatives are described first, followed by a discussion of the restraints imposed upon the model.

Model Activities

The majority of the activities in the model are the crop producing activities. They constitute 570 of the 1,075 vectors of the model. There are many possible production methods by which the desired crop output may be raised. This model is designed to include those feasible production vectors which are of interest in the context of the study. The other model vectors include such activities as input purchases, insecticide application, terrace construction, and transfer vectors.

Crop production alternatives

Crop production alternatives are defined for each of the nine soil aggregations stratified by crop rotation, tillage method, and soil conservation practice. The model is concerned with the four major field crops found in the study area, namely corn, soybeans, oats, and hay or meadow.[7] These crops are combined into the following crop rotations: corn-soybeans (CB), corn-soybeans-oats-meadow (CBOM), corn-soybeans-oats-meadow-meadow (CBOMM), corn-oats-meadow (COM), and corn-oats-meadow-meadow (COMM). In addition, the alternatives of continuous corn (C) and

[7]Corn silage is considered to be a different commodity than corn grain only for harvesting purposes. The growing activities of both are identical.

cropland pasture (M) are included. This specification allows the model to combine the rotations linearly to give other rotations not specifically included. For example, if the optimal rotation were corn-corn-corn-soybeans, it would be designated in the model by one-half unit of the corn-soybeans rotation and one-half of continuous corn.

The tillage practices used in the model are conventional tillage fall plowed, conventional tillage spring plowed, rotary-till plant, and no-till plant. Conventional tillage is defined as the practice of moldboard plowing followed by other tillage operations. All plant residue is assumed to be covered with soil. Rotary-till plant is defined to represent the practice of combining tillage and planting in one operation as in a buffalo-till planter. This alternative is assumed to leave 66 percent of the plant residue exposed. No-till plant is defined to eliminate all tillage except for planting with fluted coulters.

Several soil conservation methods are available for reducing erosion. The most effective method is terracing, which divides a tillable slope into several shorter slopes. Consequently, the runoff water is slowed and its erosive capability is reduced. The model includes terrace construction activities specific to each soil aggregation. These activities are discussed in detail later. Contouring is an additional conservation method. Under contouring, crop rows act as barriers to the overland flow and substantially reduce the amount of soil detached by runoff. Contouring may require the use of point rows which increase labor and machinery requirements since these point rows require more time for tillage operations. This increase is assumed to vary directly

with soil slope, that is, steeper slopes will have greater cost increases. Contouring is not specified for land with a slope of less than 3 percent (i.e., soil aggregations C and E). Crop tillage also may be done without regard to field slopes. This "up-and-down" or "straight-row" tillage, allowed as a practice in the model, is the most erosive of the three alternatives, but its costs are lowest.

The costs for each of the production activities are computed from several sources (Ayres, 1974a; Ayres, 1974b; Ayres, 1974c; ISU Cooperative Extension Service, 1974a; ISU Cooperative Extension Service, 1974b; James, 1973; USDA, 1975; Voss, 1973). The levels of the various inputs are determined separately for each alternative, and the costs of these inputs are then aggregated to arrive at the total production cost for each activity. This method is detailed in the following discussion.

Machine costs   Different sizes of many machines are available. Hence, a machine size is chosen to best fit the assumed size of the farm operation. Based on census data (U.S. Department of Commerce, Bureau of the Census, 1971) a farm size of 269 acres is assumed for the area. For all machines, a purchase price, expected repair cost per hours of use, and expected usable life are estimated (Ayres, 1974a; Ayres, 1974b; ISU Cooperative Extension Service, 1974a; James, 1973). Straight-line depreciation is assumed over the useful life of the implement with a salvage value determined by the type of machine and length of use (Ayres, 1974a; Ayres, 1974b). The annual cost for taxes and insurance is assumed to be 2 percent of the initial cost (Ayres, 1974a). An annualized average interest cost is computed at 8 percent per annum on the amount of the

investment over the useful life of the machine. The repair cost per 100 hours of use is computed as a varying percentage of the machine list price, depending on the machine type (Ayres, 1974a).

Tractor costs   Costs for the tractors are computed in a manner paralleling that for machinery. To account for idling time and travel to and from fields, total hours of tractor use for each production alternative are assumed to equal 110 percent of the sum of the machinery time requirements for that alternative. The economic life of the tractor is assumed to be a function of the yearly level of use, with five categories of use ranging from less than 400 hours/year on CB no-till to just over 900 hours/year on COMM conventional spring-plow.

Fuel costs   The fuel requirements for the tractor and the harvesting equipment are based on the total hours of use. The fuel costs are not added to the production costs directly, since a separate fuel purchase activity is used. This method allows obtaining model solutions with varying prices for fuel.

Labor costs   Labor requirements are assumed to be equal to the tractor hour requirements, plus an overhead requirement. The overhead requirement allows time to purchase production inputs, sell the crop outputs, and for business management generally. It is estimated to be 15 percent of the tractor hour requirement average of all production alternatives.

Fertilizer costs   Fertilizer costs are synthesized from several sources. Fertilizer recommendations are not available on a soil aggregation basis, but only on a soil series basis (Voss, 1973). Soil

series are large aggregates which may include soils on slopes which vary significantly. Since yield expectations on varying slopes within a soil series may also vary, the optimal fertilizer application in each case will differ. A higher soil slope is assumed to have slightly lower crop yields and thus require a lower fertilizer input for economically optimal use of resources.[8] The soil series fertilizer requirements, as broken down according to slope class, are combined into a weighted average fertilizer requirement for each of the soil aggregations used in this study.

The resulting rates are adjusted further downwards since not all crop acres are fertilized; the adjustment factors are taken from Census data (U.S. Department of Commerce, Bureau of the Census, 1971). In the computation of the fertilizer cost for rotations including meadow or soybeans, a fertilizer credit is given for the nitrogen carry-over produced by the legume.

Herbicide costs   The computation of the herbicide costs incorporates certain agronomic considerations. First, to avoid carry-over problems, if the rotation included soybeans, the preceding corn could not be treated with atrazine. Second, the tillage method influenced the choice of chemical; for example, Paraquat or a mixture including Paraquat is employed on no-till but not with other tillage methods. Third, a higher than average soil organic matter content requires an increased amount of herbicide. Consequently, the soil aggregations were grouped

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[8]The breakdown of soil series acreages by slope classes for the study area were obtained from unpublished data supplied by Dr. J. Highland, (Agronomy Department, Iowa State University). The adjustments in fertilizer recommendations by soil slope were suggested by Dr. R. Voss, (Agronomy Department, Iowa State University).

according to soil organic matter content in the herbicide cost computations.[9]

Other costs   The amount of corn produced by each crop rotation is multiplied by a drying cost per bushel to arrive at the total drying cost for that particular crop rotation. The seed costs are computed separately for each production activity. The assumption is made that the seed mortality would be higher on reduced-tilled ground than on conventional-tilled ground. Interest costs on long-term investments are already included in the budgets (see the discussion on machinery and tractor costs). Short-term inputs such as fertilizer, seed, herbicide, and harvest labor (particularly on hay harvesting) are employed for different time periods. Interest for fertilizer and seed investment is charged for eight months. Six months is used for the herbicide investment, two months for harvest labor and five months for fuel.

Insecticide use   Corn yields are specified in the crop production vectors under the assumption that no insecticides are applied. The potential insect problems and the amount of yield lost to insects are estimated on the basis of the specific soil, rotation, and tillage information for each such production activity.[10] The corollary to this estimate is, of course, the marginal productivity of each insecticide. Therefore, the insecticide use vectors of the model increase crop yields

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[9]Soil aggregations B, G, H, I, and K have light organic matter (O.M.) content; aggregations A, C, and F have medium O.M.; and E has heavy O.M. content.

[10]These estimates were made by Dr. H. Stockdale, Extension Entomologist, Iowa State University.

by an amount specific to each insecticide use situation. Any of the insecticides may have a different marginal productivity in different soil-tillage-rotation combinations, and a separate insecticide use vector is used in each applicable situation.

Terrace construction These activities simulate the construction of terraces on cropland. Terracing is not assumed on those soils which could not support such a practice due to shallowness of the topsoil and on the flat bottomlands. The terrace construction activity uses one acre of unterraced land and generates one acre of terraced land, i.e., increases the terraced acreage for the soil by one acre. The terracing costs, including the costs for earth work, intakes, the outlets and a limited amount of topsoiling, were computed separately for each soil aggregation by Soil Conservation Service personnel.[11]

On certain steep soils, soil slopes require use of grassed backslope terraces, that is, terraces on which the steep banks of the terrace are withdrawn from row crop production and are permanently planted to grasses. The amount of land lost from row crop production is a function of the steepness of the soil; on the steepest soils it amounts to as much as 10 percent.[12] The crop growing activities on these terraced acres are adjusted for this loss of tilled acreage; thus, for example, one acre of terraced land on soil aggregation A could produce 0.9 acres of row crops.

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[11]Received from Wilson T. Moon, Iowa State Conservationist, Soil Conservation Service, U.S. Department of Agriculture, Des Moines.

[12]The terrace specifications were determined from Soil Conservation Service recommendations (USDA, Soil Conservation Service, 1973).

Objective Function and Model Restraints

The variables in the study model are identified in Table 4. The specific functions are listed in Table 5. What is identified as the single function in Table 5 in most cases represent a set of separate but similar functions. For example, even though only a single land restraint is presented (ID 2 in Table 5), there are actually nine land restraints as a separate restraint is used for each soil aggregation.

The objective function (ID 1) specifies that the optimal solution to the model minimizes total production costs, including terrace construction costs and other input purchase costs.[13] The production costs do not include a land charge. The price of land (and the yearly land rent) depends upon the use to which that land is put. Since land use is determined by the model, a land charge cannot be specified a priori.

Separate land restraints are specified for terraced and unterraced land for each soil aggregation (IDs 2 and 3), except that the two bottomland soil aggregations (C and E) have no terraced land restraint.

Crop output demands are specified for each of the five crops (ID 4.1 to 4.5). The demands represented levels of crop production for the study area projected to 1980 based on the OBERS E' estimates (U.S. Water Resources Council, 1975).

Corn yields are estimated for each soil, rotation, tillage, and conservation method combination. The variation in crop yields by soil were derived by Rosenberry, Padgitt, and Prophet (1973). The row crop

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[13] The model also includes purchase activities for the crop outputs (at above market prices) to avoid model infeasibilities in the event of binding environmental restraints. No such infeasibilities were encountered.

Table 4. Model variables

Name	Explanation[a]
BC_s	= purchase cost per unit of crop s,
BY_s	= purchase quantity of crop s,
$CONV_i$	= conversion factor between corn grain yield (bushels) and corn silage yield (tons) on soil aggregation i,
COR_s	= crop output demand of crop s,
$CSIL_i$	= cost of harvesting one bushel of corn as silage on soil aggregation i,
DR_i	= weighted average sediment delivery ratio for soil aggregation i,
IA_{ijknpr}	= acres of use of insecticide n against insect problem complex r in use period p in rotation j on soil aggregation i with tillage method k,
IC_{ijknpr}	= application cost per acre of use of insecticide n against insect problem complex r in use period p in rotation j on soil aggregation i with tillage method k,
IP_n	= quantity of insecticide n purchased,
IPC_n	= cost per pound of insecticide n,
IR_{ijkmr}	= incidence of insect problem complex r on soil aggregation i in rotation j with tillage method k and conservation method m,
IU_{ijknpr}	= application rate of insecticide n against insect problem complex r on soil aggregation i in rotation j with tillage method k during application period p,

[a]The subscripts are:

i = 1 to 9 soil aggregations,
j = 1 to 6 crop rotations,
k = 1 to 4 tillage methods,
m = 1 to 3 conservation methods,
n = 1 to 13 insecticides,
p = 1 to 2 insecticide use periods,
r = 1 to 3 insect problem complexes, and
s = 1 to 5 crops.

Table 4 (continued)

Name	Explanation
IY_{ijknps}	= per acre marginal product (yield) of insecticide n used in insecticide use period p on crop s on soil aggregation i on rotation j with tillage method k,
FC	= price per gallon of fuel,
FG_{ijkm}	= fuel gallons required to grow one acre of rotation j on soil aggregation i with tillage method k and conservation method m,
FP	= quantity of fuel purchased,
GE_{ijkm}	= gross erosion (tons) per acre of rotation j on soil aggregation i with tillage method k and conservation method m,
$LAND_i$	= nonterraced land available for soil aggregation i,
MD	= sediment delivered to Coralville Reservoir,
PA_{ijkm}	= acres of rotation j on soil aggregation i with tillage method k and conservation method m,
PAS_i	= permanent pasture acreage on soil aggregation i,
$PAST_i$	= permanent pasture acreage on terraced land in soil aggregation i,
PC_{ijkm}	= cost of producing one acre of rotation j on soil aggregation i with tillage method k and conservation method m,
SIL_i	= bushels of corn harvested as silage on soil aggregation i,
TB_i	= acres of terraces constructed on soil aggregation i,
TC_i	= construction cost per acre of terrace constructed on soil aggregation i,
$TERL_i$	= terraced land available for soil aggregation i,
Y_{ijkms}	= yield per acre of crop s in rotation j on soil aggregation i with tillage method k and conservation method m,

Table 4 (continued)

Name	Explanation
Y_{PAS_i}	= yield per acre of permanent pasture on soil aggregation i on unterraced land,
Y_{PAST}	= yield per acre of permanent pasture on soil aggregation i on terraced land,
Z	= total production cost

yields for fall plowed activities are assumed equal to their spring plowed counterparts. The row crop yields for the reduced tillage alternatives are reduced slightly below the conventionally tilled yields.

Each crop rotation has a unique set of associated insect problems and thus requires a unique set of insecticides. Thus, the insecticide requirement equations (ID 5) are specified separately for each rotation and insect problem. Not all 13 insecticides may be present within each equation, since a particular insecticide may provide ineffective treatment for a specific insect problem.

Two equations (IDs 6 and 7) are simple inventory equations, i.e., they specify that use of the input cannot exceed purchases. The fuel restraint is expressed in gallons of diesel.

The sediment equation (ID 8) computes the amount of sediment delivered to Coralville Reservoir from the erosion (as estimated by the USLE) caused by the agricultural field crop production of the study area. The equation adds the number of tons of soil eroded by each production activity multiplied by the applicable watershed delivery ratio.

Table 5. Generalized model equations

ID	Name	Form[a]
1	Objective function	$Z = \sum_i \sum_j \sum_k \sum_m PA_{ijkm} \cdot PC_{ijkm} + \sum_i \sum_j \sum_k \sum_n \sum_p \sum_r IA_{ijknpr} \cdot IC_{ijknpr} +$
		$\sum_n IP_n \cdot IPC_n + \sum_i \sum_j \sum_k \sum_m FG_{ijkm} \cdot PA_{ijkm} \cdot FC + \sum_i TB_i \cdot TC_i +$
		$\sum_i SIL_i \cdot CSIL_i + \sum_s BY_s \cdot BC_s$
2	Land restraint (not terraced), m=1 or 2	$\sum_j \sum_k \sum_m PA_{ijkm} + PAS_i + TB_i \leq LAND_i$
3	Terraced land restraint m=3	$\sum_j \sum_k PA_{ijkm} + PAST_i - TB_i \leq TERL_i$

[a]The subscripts are:

i = 1 to 9 soil aggregations,
j = 1 to 6 crop rotations,
k = 1 to 4 tillage methods,
m = 1 to 3 conservation methods,
n = 1 to 13 insecticides,
p = 1 to 2 insecticide use periods,
r = 1 to 3 insect problem complexes, and
s = 1 to 5 crops.

Table 5 (continued)

ID	Name	Form
4.1	Crop output for corn grain (s=1)	$\sum_i \sum_j \sum_k \sum_m PA_{ijkm} \cdot Y_{ijkms} - \sum_i SIL_i \cdot CONV_i +$ $\sum_i \sum_j \sum_k \sum_n \sum_p IY_{ijknps} \cdot IA_{ijknp} + BY_s \geq COR_s$
4.2	Crop output for corn silage (s=2)	$\sum_i SIL_i \cdot CONV_i \geq COR_s$
4.3	Crop output for oats (s=3)	$\sum_i \sum_j \sum_k \sum_m PA_{ijkm} \cdot Y_{ijkms} + BY_s \geq COR_s$
4.4	Crop output for soy-beans (s=4)	$\sum_i \sum_j \sum_k \sum_m PA_{ijkm} \cdot Y_{ijkms} + BY_s \geq COR_s$
4.5	Crop output for hay (s=5)	$\sum_i \sum_j \sum_k \sum_m PA_{ijkm} \cdot Y_{ijkms} + PAS_i \cdot Y_{PAS_i} + PAST_i \cdot Y_{PAST_i} + BY_s \geq COR_s$
5	Insecticide requirement	$\sum_i \sum_k \sum_m PA_{ijkm} \cdot IR_{ijkmr} - \sum_i \sum_k \sum_n \sum_p IA_{ijknpr} \leq 0$
6	Insecticide inventory	$\sum_i \sum_j \sum_k \sum_p \sum_r IA_{ijknpr} \cdot IU_{ijknpr} - IP_n \leq 0$

Table 5 (continued)

ID	Name	Form
7	Fuel inventory	$\sum_i \sum_j \sum_k \sum_m FG_{ijkm} \cdot PA_{ijkm} - FP \leq 0$
8	Sediment delivery	$\sum_i \sum_j \sum_k \sum_m PA_{ijkm} \cdot GE_{ijkm} \cdot DR_i = MD$

IV. RESULTS OF THE ANALYSIS

The discussion in this section examines the effects of alternative policies upon the variables of the model. The model solutions are identified in the discussion by the codes shown in Table 6. The assumptions used for each solution are given in the discussion of each solution.

First, it is assumed that an absolute maximum on gross erosion per acre cropped would be imposed (alternatives B.1, B.2, and B.3). This limit is essentially an enforced change in agricultural production methods prohibiting all cropping or production alternatives that generate gross erosion in excess of the standard. This set of solutions simulates the effects of the Iowa Conservancy Law in the study area. From the standpoint of the farmer, it is the most restrictive and inflexible policy since it eliminates certain potential production alternatives from his field of choice.

A second set of solutions assumes the imposition of a limit on sediment delivered to the Coralville Reservoir, with no limits on per acre gross erosion (Alternatives C.1, C.2, and C.3). The linear programming model treats the whole study area as a single farm, a factor which is particularly significant in this set of solutions. In this solution set, gross erosion on certain acres may be quite high, since only the total amount of sediment delivered to the Coralville Reservoir is limited. Thus, heavy erosion on some acreages may be balanced by light erosion elsewhere, resulting in a total sediment load that still meets the

Table 6. Identification of computer models used in the analysis

Model identification code	Model definitions
A	Baseline model, no environmental restraints
B.1	Limit on gross erosion to 10 tons/acre/year
B.2	Limit on gross erosion to 5 tons/acre/year
B.3	Limit on gross erosion to 3 tons/acre/year
C.1	Limit on sediment delivery to Coralville to 75% of amount of baseline solution
C.2	Limit on sediment delivery to Coralville to 50% of amount of baseline solution
C.3	Limit on sediment delivery to Coralville to 25% of amount of baseline solution
D.1	Subsidy of $0.50/acre of row crops contoured
D.2	Subsidy of $1.00/acre of row crops contoured
D.3	Subsity of $1.50/acre of row crops contoured
E.1	No limit on gross erosion; subsidy of $0.50/acre row crops contoured and 33% of terrace construction costs
E.2	No limit on gross erosion; subsidy of $1.00/acre row crops contoured and 67% of terrace construction costs
E.3	No limit on gross erosion; subsidy of $1.50/acre row crops contoured and 100% of terrace construction costs
E.4	3 tons/acre/year gross erosion limit; subsidy of $0.50/acre row crops contoured and 33% of terrace construction costs
E.5	3 tons/acre/year gross erosion limit; subsidy of $1.00/acre row crops contoured and 67% of terrace construction costs
E.6	3 tons/acre/year gross erosion limit; subsidy of $1.50/acre row crops contoured and 100% of terrace construction costs

standard. Since the study area actually includes more than one farm, the implication of this condition is that the amount of permissible gross erosion varies among farmers. Since the administration of such a program presents prohibitive problems in the present land ownership structure, this set of solutions represents a theoretical alternative policy.

Two solution sets (D.1-3 and E.1-6) assume that varying levels of a subsidy would be paid to farmers to help defray the marginal costs of contouring and terracing. The cost increase of contouring is caused by increased farming time required for tillage due to possible point rows. Also, the cost of installing terraces on cropland causes a significant increase in crop production costs, even if the terracing cost is prorated to the production activities over the economic life of the terrace.

Baseline Solution

To quantify the effect of the various policies or alternatives evaluated, it is necessary to estimate outcomes which might prevail in the absence of any environmental restrictions. A baseline solution was made for this purpose (Model A). In subsequent tables the baseline results are compared with model results of the various environmental restraints.

The baseline solution assumes that no production restraints are imposed on any soil aggregations. Hence, production of particular crop rotations is concentrated on those soil aggregations which have the comparative advantage in production of each rotation. Consequently, the production of row crops is located on the soil aggregations A, B, C, and E. Other soil aggregations are cropped primarily in permanent pasture. The two bottomland soil aggregations (C and E) have crop yield limitations

due to soil wetness; these two aggregations are therefore not the locations of first choice for row crops.

The results of the baseline solution show that all tillage would use the lowest crop alternative, namely conventional till, fall plowed with no contouring. Since the objective of the linear programming model is to minimize the production cost of a minimum level of crop outputs, the model would not choose a higher cost production alternative over a cheaper one. Consequently, no contouring or spring plowing enters the optimal solution. Actually, a significant amount of spring plowing and a lesser amount of contouring are used in the study area. This variance has a practical result as it biases the results of the baseline solution somewhat in (a) slightly overestimating the gross erosion and sediment delivery, and (b) underestimating production costs of the baseline solution.

Solutions with Limits on Gross Erosion

Three solutions assume that the gross erosion for each acre cropped has to remain below specified limits. These limits are specified in three successive solutions at 10 tons/acre/year (Model B.1), 5 tons/acre/year (Model B.2), and 3 tons/acre/year (Model B.3), respectively. The specification of these limits has the effect of eliminating from consideration all crop production activities which produce soil erosion in excess of the specified amounts.

Changes in the solutions occur as a result of these erosion limits. Table 7 provides a summary of selected model results for these runs and gives a comparison with the baseline solution.

Table 7. Summary of model results assuming limits on gross erosion

Item	Model A	Model B.1	Model B.2	Model B.3
Production cost (1,000$)	62,626	64,212	67,911	73,139
Increase of production cost over model A, %	-	2.5	8.4	16.8
Total land cropped (1,000 A)	667	665	679	698
Additional terraces built (1,000 A)	0	0	172.6	222.5
Sediment delivered to Coralville Reservoir (1,000 tons)	1,136.6	364.5	193.6	104.5
Average gross erosion per acre (tons/acre)	20.0	6.1	3.1	1.6

The increase in production costs is substantial, particularly for the 3 tons/acre limit. The largest cost increase stems from the construction of terraces on about half the upland acreage. Other cost changes are attributable to the shifts in crop rotations and production methods.

A 3 tons/acre gross erosion limit decreases sediment delivered to the reservoir to about 10 percent of the baseline value. However, this decrease has significant costs per ton of sediment reduction. These costs increase as the erosion limit is tightened. From a low of $2.05 per ton of sediment reduction for the 10/tons/acre limit, the average cost per ton increases to $5.60 for the 5 tons/acre limit and reaches a maximum of $10.19 per ton at the 3 tons/acre level.

Table 8 shows the acreages of specific tillage and conservation methods for each solution. The 10 tons/acre limit could be met on all upland acres by either contouring or spring plowing or both. The acreage which remains fall-plowed with straight-row tillage throughout the solutions is exclusively located on bottomland soils.

The 5 tons/acre limit causes larger changes in tillage practices. A large portion of the newly terraced land is fall-plowed, the cheapest tillage method. Additional newly terraced acreages on more erosive land are planted by no-till methods. Other large acreages are tilled by rotary-till methods and planted on the contour. The 3 tons/acre limit extends the trend towards terracing and reduced tillage. Practically all of the upland soils are planted with reduced tillage and about one-half are terraced under this limit.

Table 8. Acres of specified practices for models assuming limits on gross erosion

Tillage and conservation practice	Model A	Model B.1	Model B.2	Model B.3
Fall-plow:				
Straight-row	574,533	128,186	146,767	146,767
Contour	0	220,470	0	0
Terrace	7,564	3,324	119,061	1,813
Spring-plow:				
Straight-row	0	0	0	0
Contour	0	228,666	173,400	0
Terrace	0	4,240	0	0
Total plowed	582,097	584,886	439,228	148,580
Rotary-till:				
Straight-row	0	0	0	0
Contour	0	0	104,733	68,821
Terrace	0	0	0	154,973
No-till:				
Straight-row	0	0	0	0
Contour	0	0	0	171,549
Terrace	0	0	61,132	73,354
Total reduced till	0	0	165,865	468,697

Table 9. Acres of specified crops for solutions assuming limits on gross erosion

Crop and soil aggregate		Model			
		A	B.1	B.2	B.3
		(rounded to nearest 1000 acres)[a]			
Corn	A	101	59	85	123
	B	199	197	171	146
	C	12	48	57	57
	E	8	16	16	16
	F	0	0	0	[b]
	G	0	0	0	0
	H	0	0	0	0
	I	0	0	0	0
	K	0	0	2	2
Total		320	320	331	345
Soybeans:	A	101	59	28	0
	B	25	27	52	77
	C	12	48	57	12
	E	8	16	16	16
	F	0	0	0	0
	G	0	0	0	0
	H	0	0	0	0
	I	0	0	0	0
	K	0 0	0	0	0
Total		145	150	153	151
Oats:	A	38	57	57	57
	B	0	0	0	0
	C	12	0	0	0
	D	8	0	0	0
	E	0	0	0	0
	F	0	0	0	[b]
	G	0	0	0	0
	H	0	0	0	0
	I	0	0	0	0
Total		58	57	57	58

[a]Totals may not add due to rounding.

[b]Less than 500 acres.

Table 9 (continued)

Crop and soil aggregate		Model A	B.1	B.2	B.3
		(rounded to nearest 1000 acres)[a]			
Hay & pasture:	A	38	91	96	91
	B	0	0	0	0
	C	48	0	0	0
	E	8	0	0	0
	F	32	32	32	32
	G	8	8	8	8
	H	6	6	0	6
	I	1	1	1	1
	K	2	0	0	0
Total		144	138	137	138

The changes in crop acreages and location of production are shown in Table 9. The 10 tons/acre limit causes a shift of row crops towards the bottomlands, that is, from soil aggregation A to aggregations C and E. Bottomlands are planted partly to oats and hay under the baseline solution. However, these crops are not grown on the bottomlands under any erosion limit. In fact, the bottomlands are planted exclusively to corn and soybeans under the two most stringent erosion limits.

Solutions with Limits on Sediment Delivery

These solutions are designed to simulate the effects of imposition of an area-wide limit on sediment delivery to the Coralville Reservoir. The delivery limit is parameterized to a maximum of a 75 percent decrease. The following discussion is limited to the more interesting changes.

The amount of sediment delivered from the study area to the Coralville Reservoir is restricted to less than 75 percent (Model C.1), 50 percent (Model C.2), and 25 percent (Model C.3), respectively, of the sediment amount of the baseline solution. No limits are placed on gross erosion per acre. Thus, it is possible that the erosive row crops could be produced with an erosive tillage method, as long as this production occurs in areas with a low sediment delivery ratio.

The summary of the results of these models is provided in Table 10. The increase in production costs due to the sediment standard is small. Production costs increase by less than 4 percent under the 75 percent reduction in sediment delivery. The production cost increase per ton of sediment reduction is small. The average cost is $0.52 per ton withheld to reduce sediment delivery by 25 percent, increasing to $1.12 per ton withheld if sediment delivery were cut in half, and increasing further to $2.78 per ton withheld if sediment delivery were reduced by 75 percent.

Under this set of solutions (C.1, C.2, and C.3), the large reduction in sediment delivery can be achieved without construction of new terraces. Changes in crop rotation and tillage methods suffice to reduce sediment delivery to the Coralville Reservoir below the stated limits. These changes in crop rotations and tillage methods are identified in Tables 11 and 12. The major change in crop rotations is an increase in production of row crops on the bottomlands (aggregates C and E). Simultaneously, the production of oats and hay on aggregate A increases, as the major rotation in this soil group becomes more extensive. The

Table 10. Summary of model results assuming limits on sediment delivered

Item	Model A	Model C.1	Model C.2	Model C.3
Production cost (1,000$)	62,626	62,775	63,264	64,994
Increase of production cost over model A, %	-	0.2	1.0	3.8
Total land cropped (1,000 A)	667	663	661	667
Additional terraces built (1,000 A)	0	0	0	0
Sediment delivered to Coralville Reservoir (1,000 tons)	1,136.6	852.5	568.3	284.2
Average gross erosion per acre (tons/acre)	20.0	14.3	9.6	4.8

Table 11. Acres of specified crops for models assuming limits on sediment delivery

Crop and soil aggregate		Model A	C.1	C.2	C.3
		(rounded to nearest 1000 acres)[a]			
Corn:	A	101	101	91	76
	B	199	199	199	177
	C	12	12	23	57
	E	8	8	8	16
	F	0	0	0	0
	G	0	0	0	0
	H	0	0	0	0
	I	0	0	0	0
	K	0	0	0	0
Total		320	320	320	326
Soybeans:	A	101	101	91	30
	B	25	25	25	47
	C	12	12	23	57
	E	8	8	8	16
	F	0	0	0	0
	G	0	0	0	0
	H	0	0	0	0
	I	0	0	0	0
	K	0	0	0	0
Total		145	145	147	151
Oats:	A	38	38	48	57
	B	0	0	0	0
	C	12	12	0	0
	D	8	8	8	0
	E	0	0	0	0
	F	0	0	0	0
	G	0	0	0	0
	H	0	0	0	0
	I	0	0	0	0
Total		58	58	56	57

[a]Totals may not add due to rounding.

[b]Less than 500 acres.

Table 11 (continued)

Crop and soil aggregate		Model			
		A	C.1	C.2	C.3
		(rounded to nearest 1000 acres)[a]			
Hay & pasture:	A	38	38	48	114
	B	0	0	0	0
	C	48	80	68	0
	E	8	8	9	0
	F	32	0	0	0
	G	8	5	3	8
	H	6	6	6	6
	I	1	1	1	1
	K	2	2	2	2
Total		144	140	138	133

largest change in tillage methods is from straight-row fall-plowing to spring plowing or contouring or both. In the most restrictive situation, almost all of the upland soils are spring-plowed and contoured. Only the most erosive soils are planted by the contour no-till method. No new terracing is needed to meet the sediment standard.

Erosion rates per acre cropped are not directly limited in this solution, since the restriction is the total sediment delivered to the Coralville Reservoir. Consequently, the gross erosion rate on some soils is relatively high; the erosion rates in Model C.3 for soil aggregations A and B are 6.1 and 6.4 tons/acre, respectively.

Solutions with Subsidies

The difference in production costs between the activities employing contouring and those without contouring is due to increased machinery and labor costs for contouring. This increase is attributable to the

Table 12. Acres of specified practices for models assuming limits on sediment delivery

Tillage and conservation practice	Model A	C.1	C.2	C.3
Fall-plow:				
Straight-row	574,533	452,399	102,746	146,767
Contour	0	52,914	389,744	0
Terrace	7,564	7,564	7,564	0
Spring-plow:				
Straight-row	0	0	0	0
Contour	0	69,220	80,648	402,985
Terrace	0	0	0	3,324
Total plowed	582,097	582,097	580,702	553,076
Rotary-till:				
Straight-row	0	0	0	0
Contour	0	0	0	0
Terrace	0	0	0	0
No-till:				
Straight-row	0	0	0	0
Contour	0	0	0	35,051
Terrace	0	0	0	4,240
Total reduced till	0	0	0	39,291

possibility of point rows occasioned by the field contour layout. These point rows require slightly more labor and machinery time during each of the tillage operations. All other production costs are not affected by contouring.

In one set of solutions (D.1, D.2, and D.3), subsidies are used to partially offset this cost increase. Since contouring is included in the model only for those soils with slopes in excess of 3 percent, the subsidies are made available only to upland crop activities. The amount of subsidy is parameterized in the models at \$0.50/acre (Model D.1), \$1.00/acre (Model D.2), and \$1.50/acre (Model D.3) of row crop contoured. In those production activities where row crops are part of a crop rotation, the subsidy per unit of the activity is adjusted to maintain the same level of subsidy per acre of row crops. The model has the choice of accepting the subsidy (and to produce with contouring) or to reject the payment (to produce crops by alternative methods).

The results of the model runs are summarized in Table 13. Since the production cost differences are generally less than \$1.00, the biggest impact may be expected to occur with a \$1.00/acre subsidy. The lowest subsidy (\$0.50/acre) is too low to offset the production cost difference between straight-row and contour tillage. Consequently, the solution at this subsidy level is identical to the solution obtained in the absence of a subsidy. At higher subsidy levels, all upland row crop production is contoured. No shift in production from one soil aggregation to another occurs, implying that subsidies are not sufficiently large to change the comparative advantage relationship among soils.

Table 13. Summary of results of models including subsidies for contouring

Item	Model A	Model D.1	Model D.2	Model D.3
Production cost (1,000 $)	62,626	62,626	62,612	62,446
Subsidy cost (1,000 $)	0	0	168	342
Total land cropped (1,000 A)	667	667	667	667
Acres contoured (1,000 A)	0	0	168	342
Sediment delivered to Coralville Reservoir (1,000 tons)	1,136.6	1,136.6	863.2	780.1
Average gross erosion (tons/acre)	20.0	20.0	14.4	13.0

A second set of solutions including subsidies (Model set E) assumes that subsidies would be paid for terrace construction as well as contouring. The terrace subsidies are expressed as percentages of the terrace construction costs specific to each soil. Three levels of subsidies are specified, namely 33 percent, 67 percent, and 100 percent of the terrace construction costs. The three levels of subsidies are compiled with either of two erosion limits, no restriction (Models E.1, E.2, and E.3) or a 3 tons/acre limit (Models E.4, E.5, E.6). It was hypothesized that the effects of the subsidy may differ under the erosion standard compared to the unrestricted solution.

A summary of the results of several of these solutions is given in Table 14. The model solutions for the lowest subsidy levels are omitted, since they present no new information (the solutions are identical) compared to their respective base solutions without subsidies. The solutions of the baseline model including subsidy payments for contouring and terrace construction are identical to the solutions obtained if subsidy payments were given for contouring alone. Thus, the subsidies available for terrace construction are not used and no terraces are constructed in the absence of soil erosion standards. The results of this run specifically indicate that the construction of terraces will not result from the mere availability of a cost subsidy, but will rather depend upon some additional impetus. This impetus may take the form of social pressure upon the landowner or some more direct pressure such as an erosion standard.

The results of the model in which subsidies are available and an erosion standard (3 tons/acre/year) is enforced bear out the last conclusion.

Table 14. Summary of results of models including subsidy payments for contouring and construction of terraces

Item	Model A	E.2	E.3	B.3[a]	E.5[a]	E.6[a]
Production cost (1,000 $)	62,626	62,612	62,446	73,139	71,038	69,631
Subsidy cost (1,000 $)	0	168	342	0	2,169	6,893
Total land cropped (1,000 A)	667	667	667	698	698	698
Additional terraces built (1,000A)	0	0	0	222.5	226.6	406.9
Sediment delivered to Coralville Reservoir (1,000 tons)	1,136.6	863.2	780.1	104.5	104.3	95.2
Average gross erosion (tons/acre)	20.0	14.4	13.0	1.6	1.6	1.5

[a] Gross erosion limited to 3/tons/acre/year.

In the 3 tons/acre/year model, the availability of a subsidy creates additional terrace construction beyond the amount required to satisfy the 3 tons/acre/year limit. In fact, at the highest subsidy level, all row crop production occurs on terraced land, except for the acreage of row crops grown on the bottomland.

V. SUMMARY

Field crop production necessarily has a very intimate interaction with the environment. The intensive production processes presently used in producing field crops can cause certain undesirable environmental by-products. These by-products may reach levels sufficiently high to cause concern about the ability of the environment to assimilate them. The by-product studied here is soil erosion. Soil erosion is an inevitable result of tilling the soil in crop production. However, soil erosion can be controlled and reduced to acceptable amounts by good management and conservation practices.

The alternative methods of causing such controls to be instituted will have various but unique effects upon the costs of production and the environment. The objective of this study is to evaluate several alternative policies which might be used to reduce soil erosion and sedimentation in the study area. The effects studied include the degree of control obtained under each policy alternative, changes in production costs, shifts in the location and methods of production and changes in land use.

The study uses a linear programming model to simulate the field crop production in a watershed of the Iowa River in East-Central Iowa.

Specifically, the study area covers 938,050 acres or about 1,466 square miles and constitutes the drainage area of the Iowa River between the Marshalltown River gauge and the Coralville Reservoir.

The restraints of the model include a crop output level which had to be obtained by the crop production processes of the model. Other agronomic and physical restraints also are specified. The objective function minimizes the costs of crop production in attaining the environmental and other restraints specified in the model.

The model results indicate that crop production costs will be increased if pollution control policies are imposed and enforced in this particular location. Table 15 shows the specific increase in production costs associated with the alternative policies. The imposition of a 10 tons/acre gross erosion limit (Model B.1) reduces the amount of sediment delivered to the Coralville Reservoir by 68 percent while increasing production costs by 2.5 percent over the baseline solution values. A 5 tons/acre limit (Model B.2) will lower the sediment delivery by 83 percent while raising costs by 8 percent over the baseline. At the 3 tons/acre limit (Model B.3), the biggest jump of costs (17 percent) is estimated; this is accompanied by a 91 percent decrease in sediment delivery relative to the baseline solution. The model (F.6) with the lowest amount of sediment delivered (a 92 percent reduction from the baseline) also shows the highest cost increase (22 percent over the baseline value).

The results of this study indicate by how much agricultural production costs in the study area could be increased by the imposition of environmental standards. Because such large cost increases could have

Table 15. Sediment delivered to Coralville Reservoir and production costs in selected models

Model	Sediment delivered	Production cost[a]
	(1,000 tons)	(1,000 $)
A	1,136.6	62,626
D.2 and E.2	863.2	62,780
C.1	852.5	62,775
D.3 and E.3	780.1	62,788
C.2	568.3	63,264
B.1	364.5	64,212
C.3	284.2	64,994
B.2	193.6	67,911
B.3	104.5	73,139
E.5	104.3	73,207
E.6	95.2	76,524

[a]Includes subsidies if applicable.

serious repercussions upon the viability of the affected farm businesses, it is imperative that a determination be made on the relationship of these costs to the environmental benefits which would accrue from a reduction of the agriculturally produced pollution. Only after such a determination can a truly optimal environmental policy be chosen.

This study was sponsored cooperatively by the Natural Resource Economics Division, Economic Research Service, U. S. Department of Agriculture, and the Center for Agricultural and Rural Development at Iowa State University. Some data are taken from a previous cooperative study of the Iowa-Cedar Rivers Basin conducted by several agencies of the U. S. Department of Agriculture. We are indebted to the Iowa-Cedar Rivers Basin Field Advisory Committee for making these data available. Specific thanks go to Paul Rosenberry and colleagues in the Natural Resource Economics Division. Our thanks also go to Wilson T. Moon, Bill Brune, Bob Boyce, Ed Burr, Russell Knutson, and the members of the River Basin Party of the Soil Conservation Service, U. S. Department of Agriculture, Des Moines.

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Models for Evaluation of Water Quality Improvements

by

Russell B. Gum and Eric B. Oswald, NRED, ERS, USDA

The title of this paper contains three major concepts which are often misunderstood by economists and even sometimes by non-economists. These are 1) models, 2) evaluation, and 3) quality. Therefore we propose the following definitions.

Quality - a measure of the goodness or badness of something. Goodness and badness, of course, are defined and completely determined by human judgements.

Model - a representation of reality, logical construct designed to predict the results of actions, system of cause and effect relationships.

Evaluation - The process of comparing the total quality of alternatives, total quality being a measure of goodness or badness defined on all aspects of the alternatives which impact human values.

Given the above definitions, the purpose of this paper is to state the evaluation problem in the context of programs and projects designed to reduce nonpoint pollution, and to provide the theory and structure for an environmental-economic model.

Criteria - the operational definition of goodness or badness.

Dollar Value - the price of a product as determined by the marketplace.
- the price a currently non-marketed product, such as aesthetics, would have if there were a market for it. (Willingness to pay if you had to buy it.)

Economic Cost - The dollar value of the resources necessary for a project.
- any reduction in dollar value of present and future outputs caused by a project.

Economic Benefits - any increase in dollar value of present and future outputs caused by a project.

Perceived Environmental Value - a measure of the quality of the environment.

Types of Evaluations:

1. Cost Effectiveness - a search for the least cost solution to meet predetermined standards, such as water quality standards, limits on erosion per acre, etc.

Advantages: Relatively simple as only costs of the program or project need be considered as benefits are assumed away by setting of standards.

Disadvantages: Benefits in the real world may bear no relationship to arbitrarily imposed standards.

2. Benefit-Cost Analysis - a search for maximum dollar benefit-dollar cost solution for all alternative projects considered.

Advantages: Such an analysis results in selection of an optimum project as all costs and benefits are reduced to a common measure dollar so that they may unambiguously be compared.

Disadvantages: It is often difficult to reduce environmental costs and benefits to dollar measures, although progress is being made in the area of willingness to pay and welfare economic analyses.

3. Environmental-Economic Tradeoff Analysis - a search for a set of solutions which for each of several levels of environmental quality a solution is found to maximize economic benefits. The policy maker is thus presented a set of tradeoffs of the following type. If a level of environmental quality of X is desired, then the best we can do economically is Y. If a level of environmental quality of X - a is desired, then the the best we can do economically is Y + b.

Advantages: The tradeoffs between environmental quality and economics are made obvious to the decision maker. The costs of improving environmental quality any given amount are obvious. Decision makers and not the analysts make the final judgement between environmental quality and economics. The measure of environmental quality does not have to be in dollar terms.

Disadvantages: The method does not result in a single solution to the problem. Environmental quality must be measured.

Given the above basic economic concepts and basic types evaluations, several obvious conclusions can be made about the evaluation of water quality improvement projects and/or programs.

Conclusion 1. If you can't define water quality, you can't evaluate.

Conclusion 2. If you can't model a cause and effect relationship between a project and/or program and water quality, you can't evaluate. At the present time it is said that we can't precisely define water quality and we can't accurately model cause and effect relationships, therefore we can't evaluate water quality improvement projects. However, the law and

basic common sense require us to evaluate water quality improvement projects. A reasonable approach to the evaluation of water quality improvements must be found. The remainder of this paper will provide suggestions for a reasonable approach based upon the environmental-economic tradeoff analysis approach to evaluation.

What is Water Quality?

In a recent report Oswald lists 35 technical parameters related to water quality (Oswald, 1978). The SEA model (U.S.D.A., 1978) can provide estimates of 5-25 different technical parameters related to water quality, depending on which chemical models you desire to include in a single model run. The ARM model (U.S.E.P.A., 1977) can provide a similar number through a more complex software system and the NPS model (U.S.E.P.A., 1979), about three relevant parameters. EPA's Storet information system defines 1800 unique water quality parameters. None of these systems, however, have provisions for measuring water quality in a manner directly useful for the evaluation of alternative projects. All of these systems measure only parameters "related" to water quality and none specify the relationship between the parameters and water quality. How can this be done?

An alternative is to define water quality in terms of the uses to which it is put. The mojor uses of water include:

1. Irrigation
2. Municipal and Industrial
3. Recreation
4. Ecosystem Maintainance
5. Power Generation
6. Flood Control
7. Drinking
8. Aesthetics

As a step toward defining water quality in general, let's first define a way to measure water quality for each of the major uses.

1. Irrigation - benefits or costs to irrigation users can be measured in dollar values related to changes in prices and quantities of output.

2. Municipal and Industrial - benefits or costs to M & I users can be measured in dollar values related to increase or reduction of treatment costs.

3. Recreation - benefits or costs ot recreation users can be measured in terms of increases or decreases in recreators' willingness to pay for the recreation experience.

4. Ecosystem Maintainance - benefits or costs to the ecosystem can be measured in terms of an index of environmental quality.

5. Power Generation - benefits or costs to power users can be measured in dollar values.

6. Flood Control - benefits or costs to flood prone areas can be measured in terms of dollar values.

7. Drinking - benefits or costs to users of drinking water supplies can be measured in terms of changes in morbidity and mortality or more simply in terms of dollar costs meeting EPA drinking water quality standards.

8. Aesthetics - benefits or costs to aesthetics can be measured in terms of an index of environmental quality.

Irrigation, municipal and industrial, power generation, drinking water and flood control can be measured directly by dollar values of market goods. Recreation can be measured in terms of willingness to pay for the recreation experience. Ecosystem maintainance and aesthetics can be measured in terms of perceived environmental indices.

Thus, we have three types of measures of water quality: dollar values of market goods, dollar value of recreation experience, and perceived environmental indices.

If we combine the dollar value measures, we can define water quality in terms of dollar values and an index of environmental quality. Economists have reasonably standard models and procedures for estimating changes in dollar values, but methods to estimate changes in environmental quality indices have only been developed in the last ten years.

Measuring Environmental Quality

In order to measure environmental quality, four concepts must be defined and linked together. The concepts are goals, subgoals, technical indicators, and plans. The linkages are the plan to technical indicator link (plan impacts), the technical indicator to subgoal link (perceptual impacts), and the inferior subgoal to superior subgoal link (value impacts). The concepts are organized in a hierarchical structure of goals, subgoals, and technical indicators where information from lower levels is aggregated to form the information for the higher levels of the hierarchy. The general structure of the system is displayed in Figure 1.

Definitions

Goals-"Goals are positive attributes or characteristics for which individuals or society strive. While word stated, they are generally beyond precise meaning, and broad enough so that unanimity of acceptance is achieved for each goal." (Technical Committee 1974, p.3) An objective is associated with a specific project or action, while a goal is a more general concept and stands independent of any specific policy or action.

Subgoals—A portion of the general attribute a goal describes. For example, water quality is a subgoal of environmental quality.

Superior subgoals—More general subgoals, i.e., higher up the goal hierarchy.

Inferior subgoals—Less general subgoals, i.e., lower down the goal hierarchy.

Directly perceived subgoals—The lowest level (most inferior) subgoal on any branch of the goal hierarchy. Achievement of this subgoal can be perceived directly by people, without technical measurement.

Technical indicators—A technical measure related to the condition or state of the directly perceived subgoals.

Plans—All alternative plans or policies to be evaluated. These plans will directly affect the state of the directly perceived goals.

Value connective—The preference function which allows the state of a superior subgoal to be defined as a function of the states of the corresponding inferior subgoals.

Perceptual connective—The function which allows the state of a directly perceived subgoal to be defined as a function of the corresponding technical indicator(s).

Impact connective—The function which allows the state of a technical indicator to be defined as a function of the plan or policy to be evaluated.

The information flow of such a system is outlined in Figure 2. The first step (step 1, Figure 2) is to develop a list of human goals for environmental quality. The form of the goal list is that of a hierarchy; abstract or general goals are disaggregated into more specific goals until a level of disaggregation is reached where lower level goals can be perceived directly. At abstract levels goals describe very general attributes or characteristics for which people strive; at the directly perceived subgoal level they describe specific components of the abstract goals. For example, the general goal of environmental quality has a superior subgoal of water quality with an inferior subgoal of water aesthetics, which is further disaggregated into the directly perceived subgoals of odor, clarity, and floating objects. The clarity subgoal has a corresponding technical indicator of turbidity measured in Jackson Candle units. Using this structure, any number of alternative plans to improve water quality could be evaluated in terms of the hierarchical system. Such evaluations would result in relating plans to measures of turbidity to perceived changes in clarity to changes in the social goal of environmental quality. Odor and floating objects also have their own technical measures and would contribute to the evaluation through the relevant connectives.

Although goals describe, rather than evaluate, the strivings of an individual or group, they are not value free. Social relevance—the fact that goals represent ideas for which people strive—results in values being ascribed to goals. Thus, the second step (step 2, Figure 2) of the process is to assess the values or relative importance of various goals and goal components. This assessment is accomplished empirically by developing preference functions which relate goals to a person's or group's preference for a situation. For example, a preference function would be defined relating the levels of water odor, clarity, and floating objects to satisfaction with water aesthetics. Additional preference functions would be defined relating the importance of aesthetics to water quality, which in turn is one of the components of the environmental quality goal. This step can be accomplished either by public input (e.g., surveys) or by a group of experts developing such functions. However, since technical matters are not involved in determining the relative importance among perceived goals, public input is the most valid source of such information. Furthermore, if public input is obtained, differences in preferences among various public groups can be examined.

Step 3 is to develop a set of technical indicators, i.e., measurable features of the directly perceived subgoals which would be affected by the proposed plan. The planner then makes an estimate of the level of the technical indicator resulting from each of the alternative plans.

In the fourth step the set of technical indicators is related to the hierarchy of human goals. Measures of the impact of changes in the technical indicators on human goals are made. Both public and technical opinions are important in this regard. In some cases, public inputs may be most salient, e.g., in judging scenic quality of public lands. In other cases, e.g., evaluation of environmental health and safety subgoals, the public may lack the knowledge and expertise necessary to select among alternative plans; however, they still may be able to express preferences for the general health and safety goal relative to other goals (step 2).

From this information a final set of environmental impacts can be provided to the decisionmaker (step 5).

At this point we have defined water quality in terms of its eight major uses, and reduced these measures to a measure of dollar value and a measure of an environmental index. Given these two measures a tradeoff analysis can be used to determine potentially good alternatives and such information presented to the decision makers if the necessary information to relate the results of the alternatives to the measures of water quality for each of the eight major water uses exists.

Cause and Effect Models

Cause and effect models can be categorized in three types.

1. Action-> Field Response
2. Field Response-> Waterway Response
3. Waterway Response-> Water Quality Response

It is obvious that all three types of models or a single model combining all three types of cause and effect relationships are necessary for the evaluation of water quality improvement projects. Unfortunately, such an integrated model currently exists only in prototype form. Models of the first type exist in usable, although not perfect, form. SEA, Universal Soil Loss Model, ARM, and NPS model the physical impacts of pollution control actions, and linear programming models exist to model the economic impacts of such actions at the farm level.

At the second level, field to waterway response, current efforts to model watersheds appear likely to produce usable models of the transport of pollutants from the land into water bodies. Again, linear programming models exist to model the economic impacts at the watershed level.

Models currently exist only in prototype form at the third level, relating the changes in water quality parameters to the uses of the water and specifically to changes in the economic and environmental measures related to these uses. Models need to be developed to estimate how pollutants impact the values of the eight major water quality uses. Prototype models of this type include:

Salinity vs. Irrigation
Pollutants vs. M & I Treatment Costs
Pollutants vs. Recreation
Sediment vs. Flood Control
Pollutants vs. Aesthetics
Pollutants vs. Ecosystem Maintainance

Obviously, for a comprehensive evaluation of water quality improvement projects, all of the above need to be considered. (Some, of course, will not apply to specific areas or projects.) As demonstrated from the list of models above, it is not necessary or even desirable to start from scratch and build a model to relate changes in water quality parameters to water uses, but the important task is to synthesize existing models into a comprehensive and consistent model of the cause and effect relationships.

Modeling - Monitoring - Reliability
Statistical Confidence - Value of Information
Loss Function, Types of Errors.

What criteria should we use to judge the quality of the evaluation effort itself? Some have suggested that statistical reliability is the only or at least the most important criterion. Balderdash! Even from a statistical point of view the confidence interval around the estimate is not the appropriate measure of the quality of a statistic. Just like water, the quality of a statistic can only be The cost of not making a judgement and the costs of collecting and analyzing the basic information itself must be considered. It is nice to be right ninety-five percent of the time, but it's silly to insist on such precision, if, by being right only seventy-five percent of the time, society will be better off. Therefore, the statistical concepts of value of information and loss functions are relevant to the problem of evaluation. The concept of ninety-five percent confidence level is not!

In terms of evaluation models this implies that sensitivity analysis be run on all of the components of the model. Those components which do not impact the ranking of alternatives obviously warrant less effort in making them precise predictions or reality than those components which have large impacts on the ranking of alternatives. Any other process of determining the necessary statistical reliability of a model component is simply not scientific and will lead to social costs. It must be remembered that there are four, not one, types of statistical errors:

1. Accepting a false statement.
2. Rejecting a true statement.
3. Solving the wrong problem.
4. Solving the right problem too late.

Linked Economic-Environmental System for Evaluation of Nonpoint Pollution Control Programs

The purpose of this section is to (1) define the structure of a Linked Economic-Environmental System for Evaluation of Non-point Pollution Control programs, (2) define the necessary inputs and planned outputs of the system, and (3) discuss the availability of a data base to test and calibrate the system.

System Structure

The overall evaluation system is composed of seven major subsystems. (See Figure 3)

1. Agriculture Production
2. Land Quality
3. Water Quality
4. Environmental Impact
5. Economic Impact
6. Evaluation
7. Control

Agriculture Production Subsystem

The Agriculture Production Subsystem contains the following models:

1. Best management practices, costs and results.

The best management practices, costs and results model estimates the costs to both the government and to farmers of BMP's and also estimates the physical results of best management practices on Land and Water Quality parameters.

2. Farm costs and returns

The farm costs and returns model estimates the economic impact on individual farmers of implementing BMP's.

3. Cost share acceptability

The cost share acceptability model relates the number of farmers who will implement BMP's given any proposed cost share system.

4. Standards and regulations

The standards and regulations model allows for estimating the impacts on implementation of BMP's by enforcement of water quality standards or land use regulations.

5. Aggregated supply and demand

The aggregate supply and demand model estimates the impact of implementation of BMP in a particular area on the aggregate supply and demand for food and fiber products.

Land Quality Subsystem

1. Upland habitat model and wetland habitat model

The habitat indices are based directly upon work of the Project Impact Evaluation Team of the U. S. Fish and Wildlife Service and their Habitat Evaluation Procedures (U. S. Fish and Wildlife Service, 1978).

2. Land Productivity Model

The land productivity model relates changes in land use and implementation of BMP's to the years of topsoil remaining in the project area.

3. Pesticide Model

The pesticide model estimates the quantities of foliar-applied and soil-applied chemicals in storm runoff, partitioned between solution and water phases, as a function of past and present land uses and implementation of BMP's.

Water Quality Subsystem

1. Hydrology model

The hydrology model relates precipitation events to runoff, infiltration and stream flows.

2. Nutrient model

The nutrient model relates land uses, BMP implementation and hydrology to quantities of nutrients in stream flows.

3. Sediment model

The sediment model relates land use, BMP implementation and hydrology to quantities and physical character of sediments in stream flow.

4. Pesticide model

The pesticide model relates land use, BMP implementation and hydrology to types and quantities of pesticides in stream flow.

5. Aquatic habitat model

The aquatic habitat model relates nutrients, sediment, pesticide-herbicide concentrations, and hydrology to aquatic habitat index. This model is based directly upon the work of the Habitat Evaluation project of the Fish and Wildlife Service.

Environmental Quality Subsystem

The environmental quality subsystem relates the physical and biological impacts of a control program to people's perceptions and values for environmental quality. A goal structure such as the one in Figure 4 will be developed and environmental quality defined in terms of the components of the goal structure using the S.Q.P.I.-TECHCOM methodology (Arthur et al, 1976 and Technical Committee, 1974).

Economic Welfare Subsystem

The economic welfare subsystem will estimate economic impacts of control alternatives for all segments of society directly impacted. Models within the economic welfare subsystem include:

1. On farm economic impact model

This model will estimate the expected changes in farm costs and returns and land values due to implementation of pollution control programs.

2. Government cost model

This model will estimate the local, State, and Federal costs incurred by the pollution control program.

3. Recreation benefits model

The recreation benefits model will estimate the change in consumers' surplus for recreation experiences as a direct result of implementation of nonpoint pollution control programs.

4. Reduced salinity benefits model

The reduced salinity benefits model estimates increases in downstream agricultural production due to reduced salinity resulting from pollution control programs.

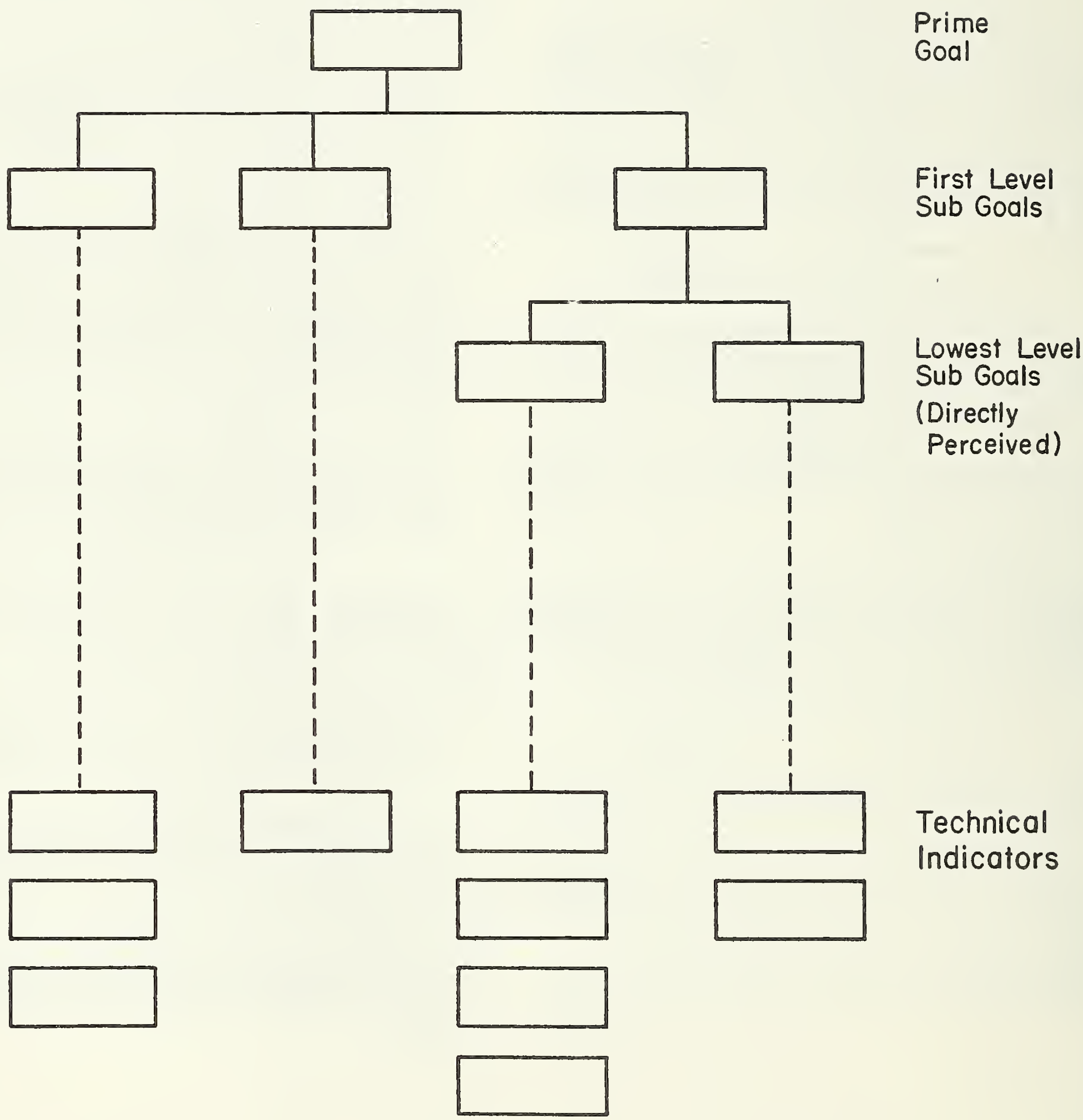

Figure I.
A GOAL HIERARCHY

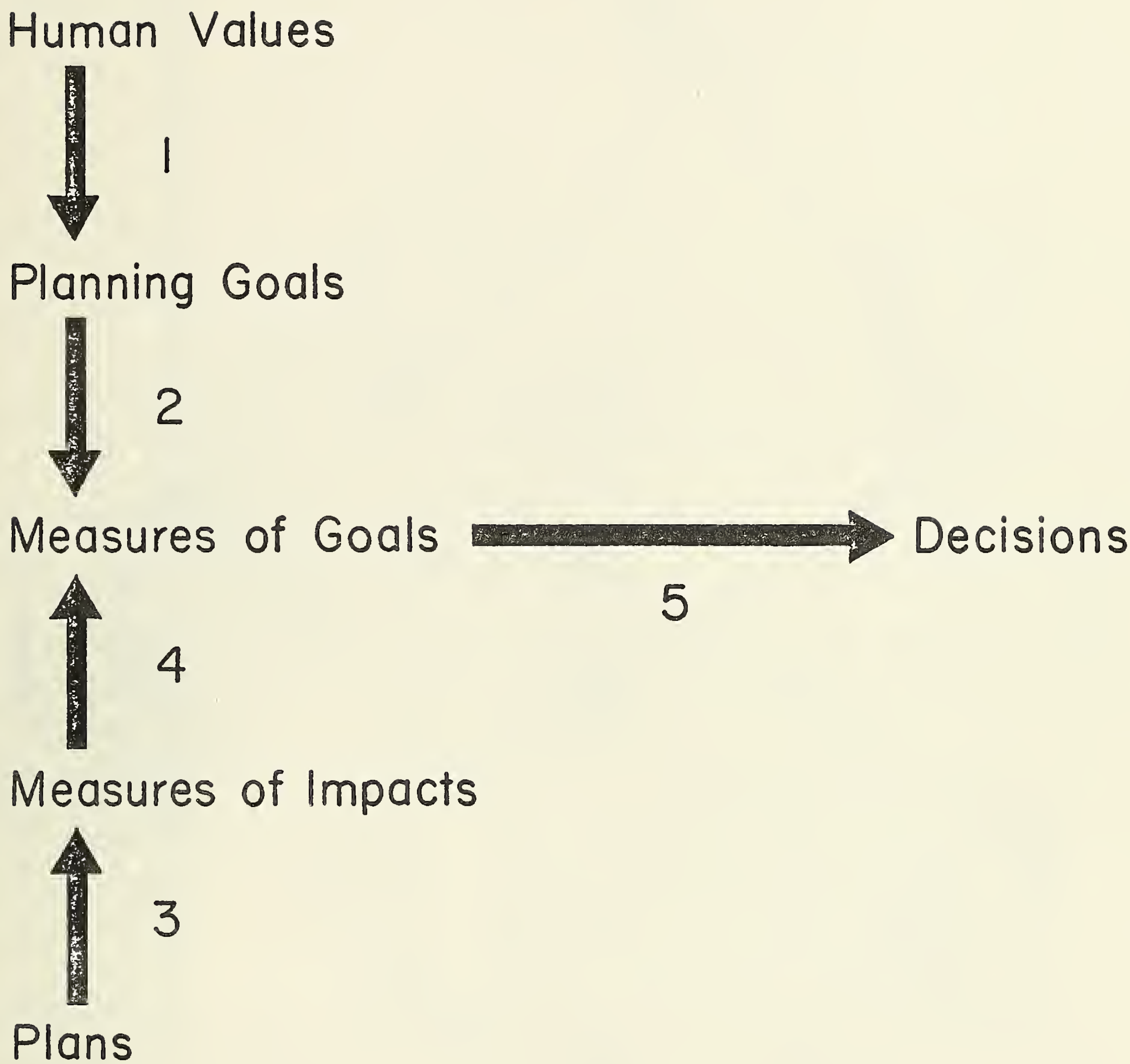

Figure 2.
INFORMATION FLOWS

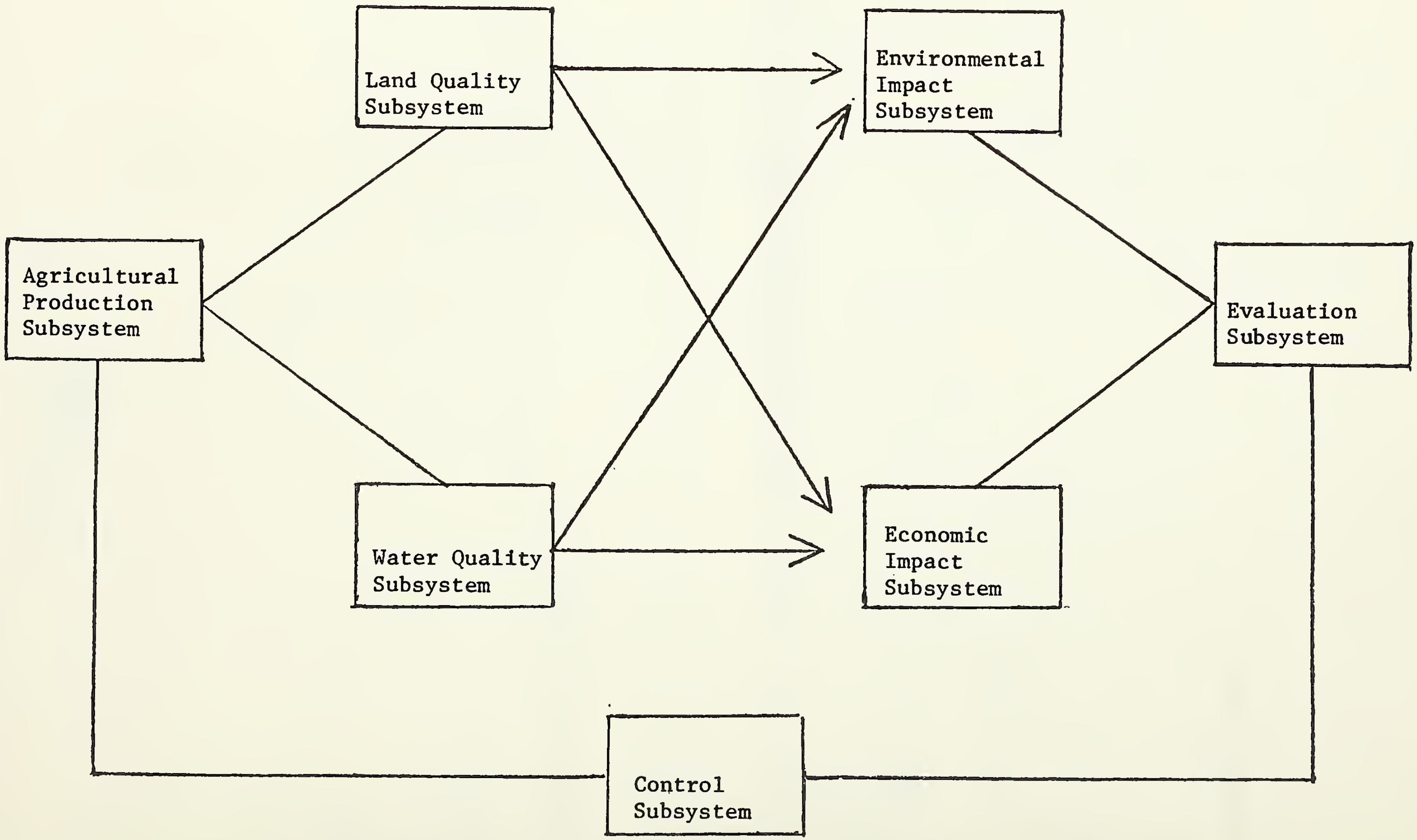
Land Quality
Subsystem
Environmental
Impact
Subsystem
Agricultural
Production
Subsystem
Evaluation
Subsystem
Water Quality
Subsystem
Economic
Impact
Subsystem
Control
Subsystem

Figure 3.

GOAL STRUCTURE

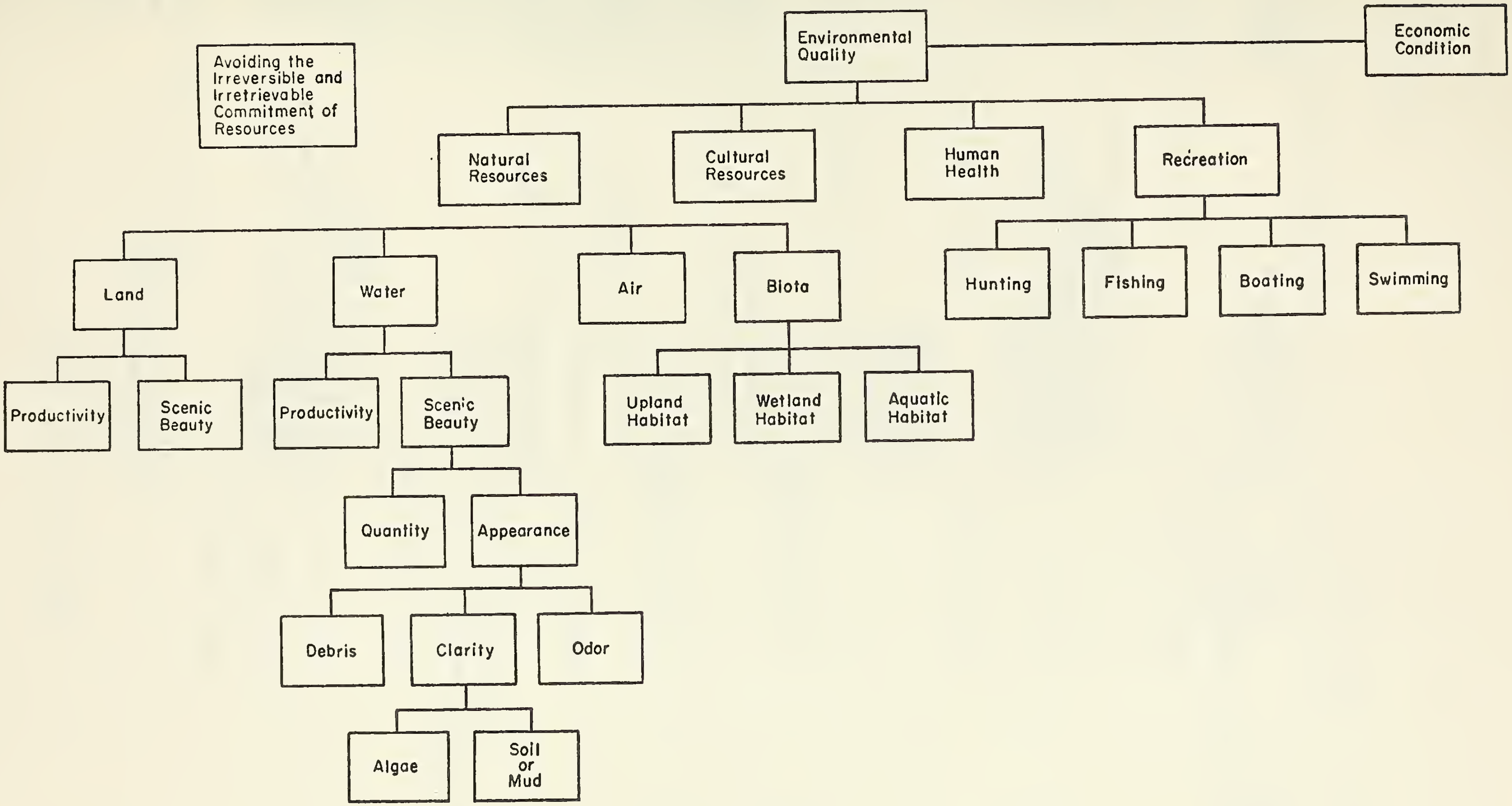

Figure 4

Table 1. System inputs.

Subsystem	Model	Input requires	Availability from SCS study
Agricultural Production			
	BMP costs and results		
		List BMP practices	yes
		Capital costs of BMP's	yes
		Maintenance costs of BMP's	yes
		Impact on sediment of BMP's	yes
		Impact on runoff of BMP's	yes
	Farm costs and returns		
		Farm budgets	yes
		Crop yields	yes
		Crop prices	yes
		Input prices	yes
	Cost share acceptability		
		Cost share formula	yes
		Farmer survey	no
	Standards and Regulations		
		Water quality standards	no
	Aggregate supply and demand		
		Aggregate supply and demand functions	no
Land Quality Subsystem			
	Upland habitat model		
		List indicator species	no
		List biological parameters	no
		Species-parameter relationshisp	no
		Measures of changes in biological parameters	no
	Land productivity model		
		Physical soil data	yes
		Slope data	yes
		Cover data	yes

Table 1 (cont'd.)

	Pesticide-herbicide residues model		
		Soil residues	no
		Chemical applied	no
		Chemical characteristics	no
Water Quality Subsystem			
	Hydrology model		
		Precipitation probabilities	yes
		Stream flows	yes
		Infiltration rates	yes
	Nutrient model		
		Fertilizer use	yes
	Sediment model		
		Stream flows	yes
		Sediment discharges	yes
	Pesticide-herbicide model		
		Chemicals applied	yes
		Chemical characteristics	no
	Aquatic habitat model		
		List indicator species	no
		List biological parameters	no
		Species-parameter relationships	no
		Measures of changes in biological parameters	no
Environmental Quality Subsystem			
		Public perceptions of environmental quality	yes
		Public values towards changes in environmental quality	yes
Economic Welfare Subsystem			
	On farm economic impact model		
		Land values	no
		Historical farm incomes	no

Table 1 (cont'd.)

Government cost model		
	Tax sources	no
	Program costs	yes
Recreation benefits model		
	Visitor days by activity	no
	Consumer surplus measures	no
	Changes in participation	no
Reduced salinity benefits model		
	Changes in farm income due to reduced salinity	no
Reduced sediment benefits model		
	Changes in reservoir capacity due to silting	no
Reduced treatment cost model		
	Changes in water treatment needs	no
Reduced health cost model		
	Incidence of non-point pollution related diseases	no

5. Reduced sediment benefits model

The reduced sediment benefits model estimates the benefits or costs of reduction in sediment due to non-point pollution control programs.

6. Reduced treatment cost benefits

This model estimates the reduced treatment costs incurred by downstream water users due to pollution control measures.

7. Reduced health costs model

The reduced health costs model estimates the economic value of better health of downstream water users due to reduction in pollution levels.

Evaluation Subsystem

The evaluation subsystem is composed of a non-linear programming model which will maximize an environmental quality index for alternative levels of net economic costs.

Control Subsystem

The control subsystem allows modification of the restraints in the mathematical programming model so that changes in water quality standards, and/or cost share procedures can be evaluated.

System Inputs and Outputs

Outputs of the system would include summary measures of environmental and economic impacts of a non-point pollution control program. In addition to the summary measures, options would be available for a user to retrieve detailed information of the outputs and inputs to any of the subsystems and models within the system.

Input to the system is listed by subsystem and model in Table 1.

Availability of Data

As can be seen from Table 1, a large part of the data needs for developing and testing a system model for non-point pollution control evaluation are currently being collected as part of the cooperative river basin project on the Columbia Plateau. Additional data would have to be collected to develop and test a complete system.

Conclusion

At the present time the American public is tired of increased government spending and increased government red tape and regulation. If we are proposing to increase both of these "bads" for the sake of improving water quality, it is obvious that we will be required to demonstrate the extent of, and, more importantly, the value of such improvements. To do this requires the development, testing, and implementation of an evaluation model as outlined in this paper. Anything less, such as assuming reduction in erosion is proportional to increase in water quality, will not meet the standards of evaluation required by law nor will it reflect the perceptions of the public thus generating further distrust of Federal Government.

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The National Water Data Network

by

F. P. Kapinos

U. S. Geological Survey, Reston, Virginia 22092

Abstract. In 1964, the Bureau of the Budget issued Circular A-67 to coordinate water-data acquisition activities by Federal agencies. Under Circular A-67, the Department of the Interior's Office of Water Data Coordination has the responsibility to: (1) maintain a catalog of information on water data, (2) undertake a continuing review of water-data requirements, (3) prepare a Federal plan for efficient utilization of water-data activities, and (4) design a National Water Data Network. A concept of three levels of information was developed as the rationale for national network planning. The three levels are: Level I—a base level of information for national and regional planning and assessment; Level II—data needs for subregional planning and assessment; and Level III—data for operation and management at the local level. Several elements of Level I of the national network have been totally or partially implemented, including: (1) the streamflow and stream-quality accounting elements; (2) the water-use accounting element; (3) the water-quality surveillance element; and (4) the flood surveillance element.

Introduction

In 1964, in an effort to meet the needs for water data in the most efficient and economical way possible, the Bureau of the Budget (now the Office of Management and Budget) issued Circular A-67 that prescribed guidelines for coordinating water-data acquisition activities of the more than 30 Federal agencies that collect and (or) use water data. Included in these activities are processing, storing, and disseminating water data, as well as collecting quantitative and qualitative data on the Nation's streams, lakes, reservoirs, estuaries, and ground waters.

Responsibility for implementing Circular A-67 was assigned to the Department of the Interior's U.S. Geological Survey, which in turn established the Office of Water Data Coordination (OWDC). Principal lead-agency responsibilities are to: (1) maintain a catalog of information on water data and on Federal activities being planned and conducted to acquire water data; (2) undertake a continuing and systematic review of water-data requirements; (3) prepare and keep current a Federal plan for efficient utilization of water-data acquisition activities; and (4) design and operate a national water data network.

Designing the National Water Data Network

There are several ways to approach the design of hydrologic networks. In the ase of the National Water Data Network, the Geological Survey set objectives by using a stepwise process that involved (1) determining the status of data on hand, (2) forecasting the needs for data, and (3) designing programs to meet these needs.

The conceptual model of the national network defines three levels of information (Figure 1) that correspond to the amount of detail needed for planning. Level I is a base-level of information for national and regional planning and assessment, and provides the foundation for more detailed and precise activities. Information at this level is uniform nationwide and should be sufficient for a general estimate of the water-resources quantity and quality in any given place at any given time. Level II consists of data for water-resources planning and assessment within a subregion, commonly a major stream basin. Information at this level is nonuniform nationwide and responds to the needs within each subregion. Level III comprises data for water-resources operation and management at the local level. Information at this level responds to operational needs as they arise, and is consequently nonuniform from area to area.

The national network concept also incorporates three functional categories: (1) periodic accounting of the resource; (2) surveillance of principal hazards; and (3) a real synthesis of information to describe the whole system and to interrelate the parts.

Planning the National Network

In planning Level I of the network, the Survey used the 21 regions and the 222 subregions established by WRC as the framework for national assessments. The subregions were further subdivided into 352 accounting units (Figure 2) for planning the Level I accounting functions.

Recently, hydrologic subdivision of the country has been refined through a nationally coordinated effort aimed at developing a series of State Hydrologic Unit Maps depicting commonly agreed-upon boundaries and numerical codes for river basins. The four-color maps present information on drainage, cities, political boundaries, and hydrologic boundaries of: (1) water-resources regions; (2) water-resources subregions;

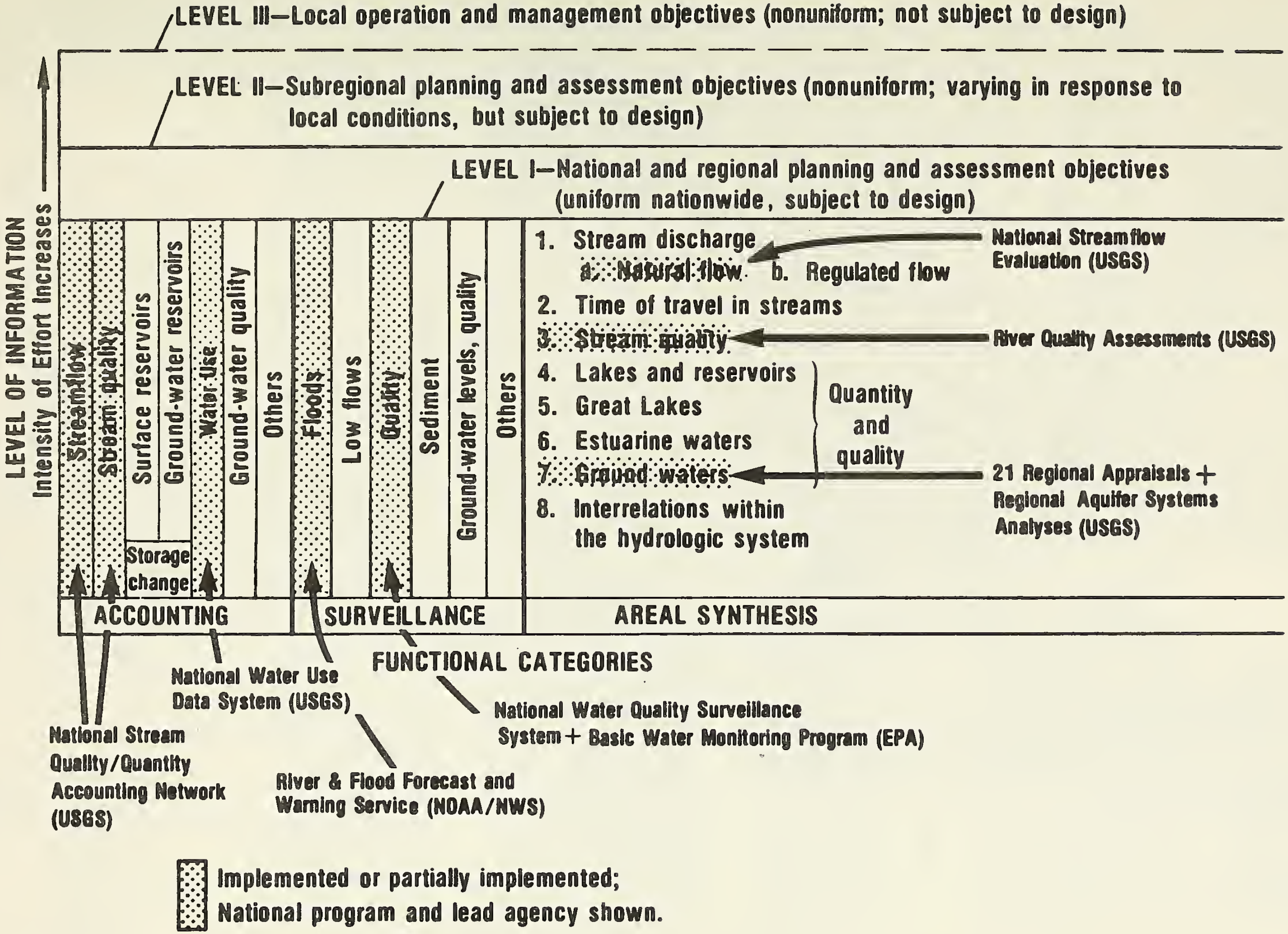

Figure 1.--Conceptual model of the National Water Data Network.

(3) accounting units of the National Water Data Network; and (4) cataloging units of the Catalog of Information on Water Data. The maps depict hydrologic unit boundaries and 8-digit codes for each river basin draining more than about 700 square miles. The 2,150 cataloging units at this level of subdivision are expected to be adequate for the Level II planning framework within the subregions. Additional subdivision and codification of the cataloging units is being carried out by several Federal agencies (including the U.S. Soil Conservation Service and the U.S. Forest Service) and by State agencies.

The hydrologic units are also being depicted on maps at a scale of 1:250,000 by the Geological Survey's Geography Program to portray land use and land cover for the entire country. In addition to land use information and hydrologic unit boundaries, these maps show political boundaries and county subdivisions, including census tracts and Federal land ownership. With these maps, hydrologic and water-quality data can be related to land use and land cover data as well as to socioeconomic data compiled by census tract. All of this information is being digitized to improve the capability for computer retrieval and analysis of the data.

Implementing the National Network

To date, implementation of the National Water Data Network has focused on Level I objectives, i. e., national and regional planning as shown in Figure 1. Stations were selected to meet the objectives for two of the accounting functions—streamflow and stream quality. For these elements of the network, the principal concern is to obtain a measure of the quantity and quality of water in major streams moving from one accounting unit to another and leaving the country.

In January 1973, the Survey began implementing the National Stream Quality/Quantity Accounting Network (NASQAN) at 50 stations by acquiring the streamflow and water quality data needed to bring the stations up to the desired level. By September 1978, the number of active stations had increased to 445. Additional stations needed to account for the quality and flow mainly in the coastal units have been added in fiscal year 1979, bringing these two elements of the Level I accounting network up to the planned level of 518 stations. In implementing these elements of the network, ongoing data activities of Federal and non-Federal organizations have been incorporated wherever possible.

Several reports have been published that summarize the results for the first few years of operation of the NASQAN network, such as the reports by Hawkinson and others (1977) and Briggs and Ficke (1977). Figure 3, for example, shows how data are used to portray certain water-quality conditions throughout the Nation for 1975. Subsequent reports will update the water-quality picture on an annual basis. Data from NASQAN have been used for the CEQ

The water-use element of Level I accounting is currently being implemented with the development of the Survey's National Water Use Data System. This program, carried out in cooperation with State agencies, was established in fiscal year 1978 to collect, store, and disseminate water-use data to complement data on the availability and quality of the Nation's water resources. The primary objectives of the system are: (1) to account for the water used throughout the United States, (2) to organize the data collected so that the data will be uniform in quality, and (4) to provide the necessary information to update and make projections of future water requirements.

The Geological Survey has completed a series of summary appraisals of the ground-water resources of each of the 21 major water-resources regions. Together with the studies of regional aquifer systems, a program that is just getting underway, this series of regional appraisals will constitute the ground-water component of the Level I areal synthesis element.

The Regional Aquifer-Systems Analysis program includes those aquifer systems shown shaded in Figure 4. Although each regional aquifer study will be designed to fit the particular problems of the study area, the general approach will be to develop a computer simulation for the overall aquifer system, supported by more detailed simulations of local or subregional problem areas. These simulations will serve a twofold purpose: (1) they will assist in forming an understanding of the natural (prepumping) flow regime, and of the changes brought about in it by human activities; and (2) they will provide a means of predicting hydraulic effects of future pumpage, artificial recharge, waste disposal or other stress, and will consequently provide some of the basic information required for water management.

Many agencies' water-data programs are included in the National Water Data Network. For example, the Tennessee Valley Authority, the U.S. Army Corps of Engineers, and Environment Canada provide data on streamflow and stream quality at several NASQAN sites, and other agencies provide coverage for some of the Level I elements. The U.S. Environmental Protection Agency's National Water Quality Surveillance System (NWQSS) and its Basic Water Monitoring Program (BWMP) provide data for the water quality surveillance element of the network. Portions of these two programs are carried out in cooperation with Geological Survey and State water agencies.

The National Oceanic and Atmospheric Administration's National Weather Service (NWS) maintains a River and Flood Forecast and Warning Service that provides the data for the flood surveillance element of the Level I network. This program is carried out in cooperation with the Geological Survey, the Corps of Engineers, the Tennessee Valley Authority, the Bonneville Power Administration, and other agencies that provide river stage and discharge information

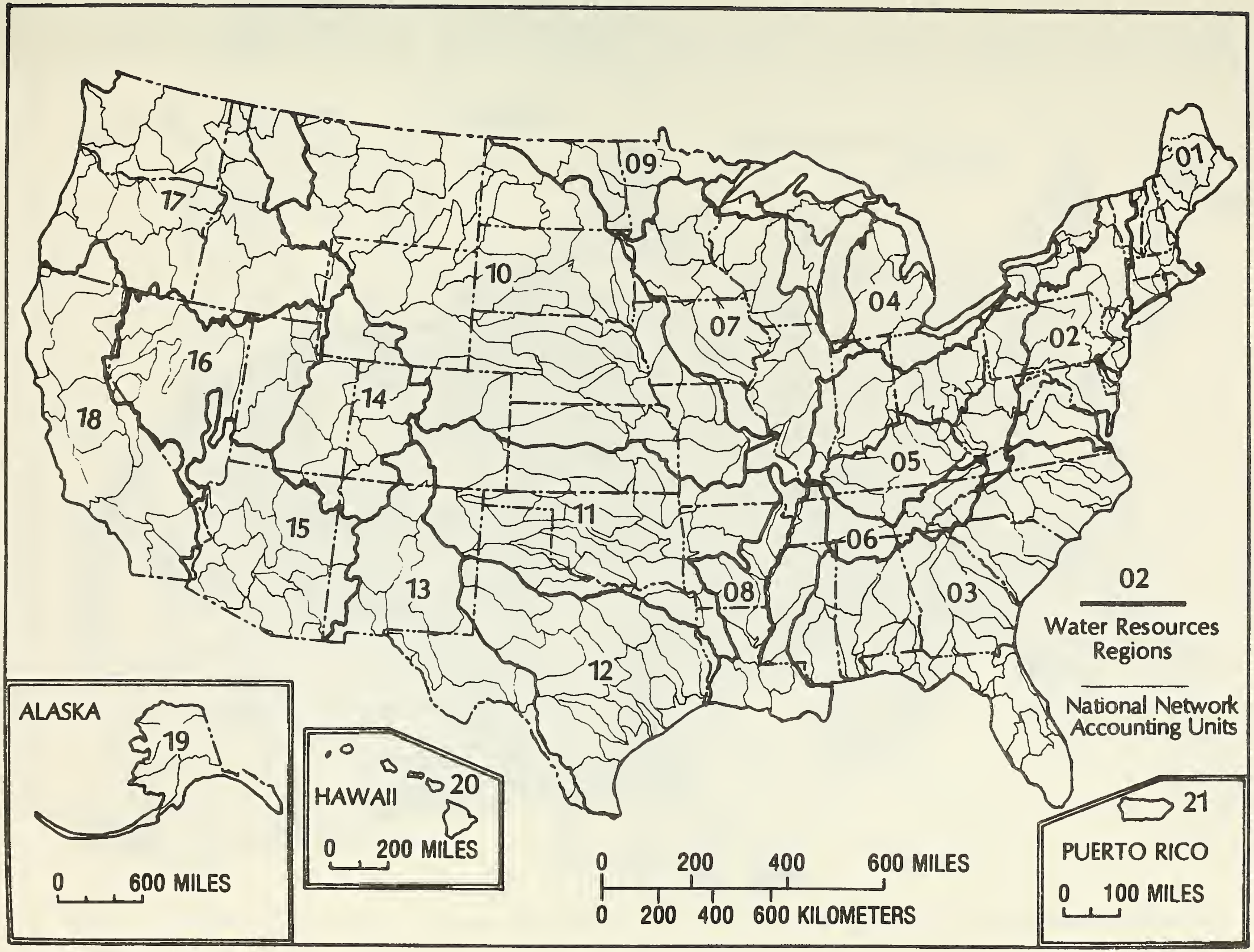

Figure 2.--Accounting units of the National Water Data Network.

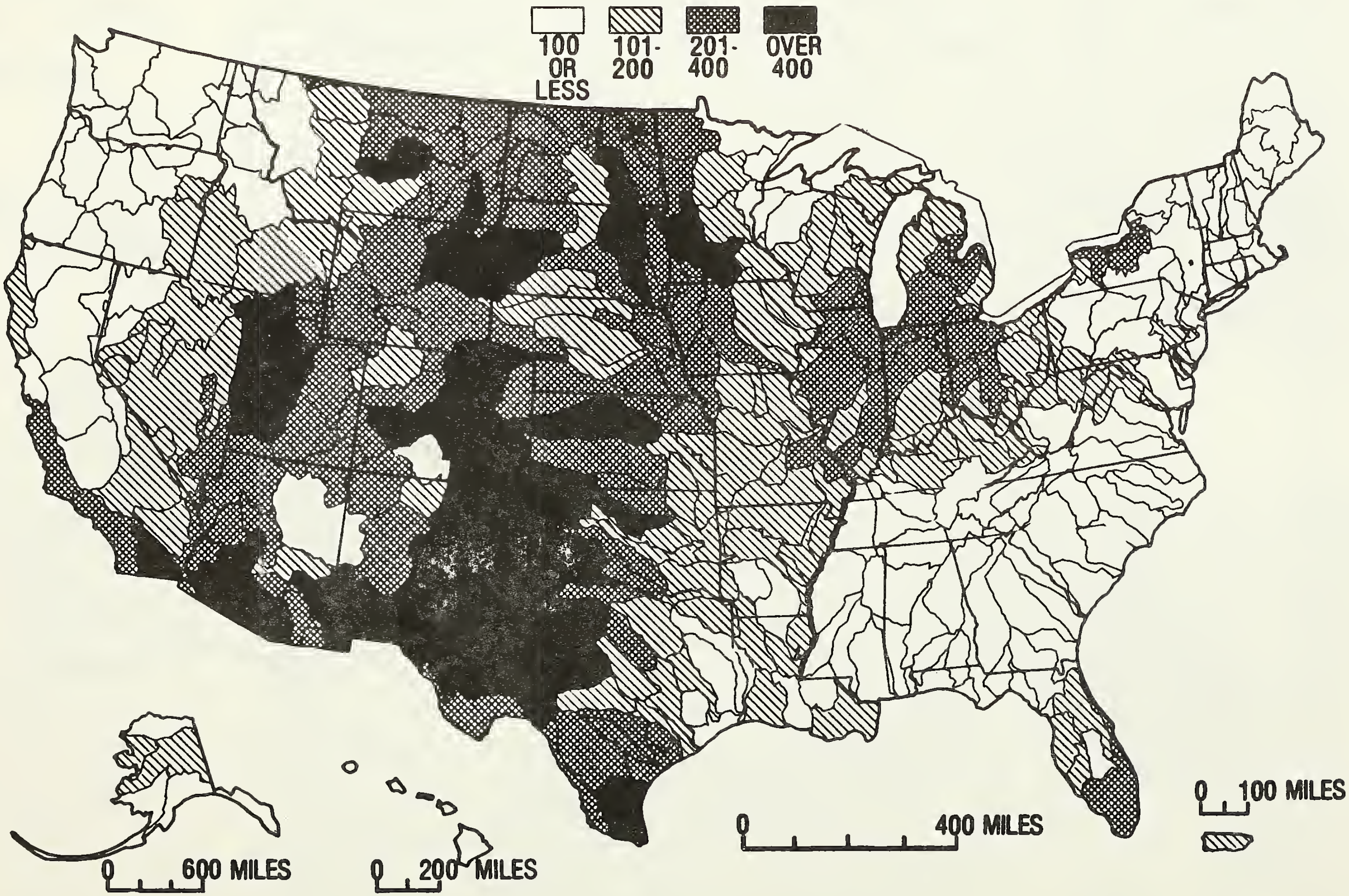

Figure 3.--Mean hardness as calcium carbonate in milligrams per liter at NASQAN stations during the 1975 water year. Each accounting unit is shaded to show mean hardness for the NASQAN station(s) representing that unit.

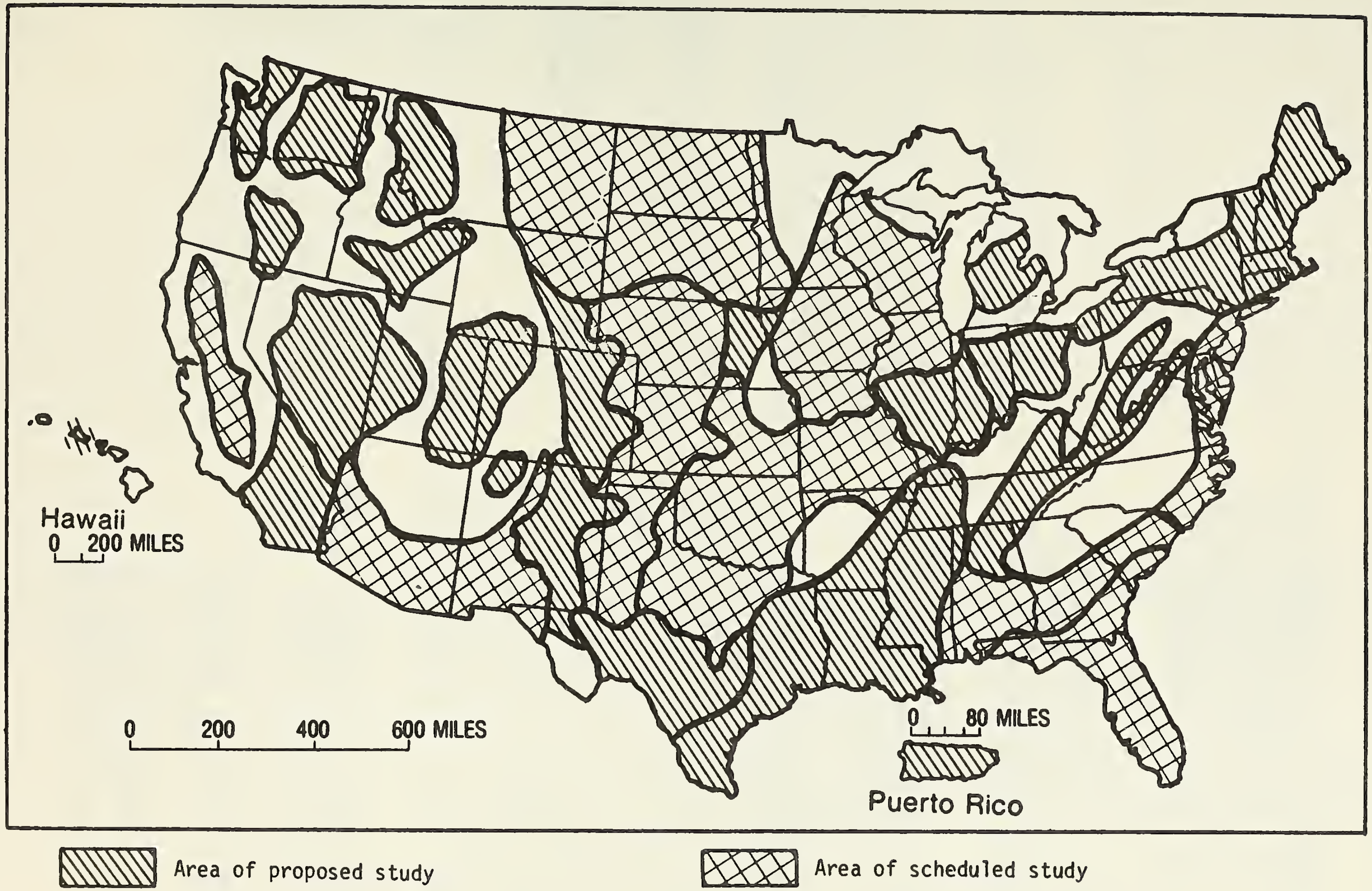

Figure 4.--Study areas of the Regional Aquifer Systems Analysis program of the Geological Survey.

to NWS. The system provides early forecasts and warnings for pending flood events from 12 River Forecast Centers.

Summary

The National Water Data Network comprises many different elements, some of which have yet to be designed and implemented. In carrying out its responsibilities for network design, the Geological Survey relies heavily on the cooperation of the many Federal and non-Federal agencies involved in the coordination activity to identify their present and anticipated needs and to coordinate their ongoing and planned activities to best meet these needs.

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Economics of Water Quality Monitoring

Lee Christensen, NRED, ERS, USDA

This conference focuses on modeling and monitoring from the perspective of agricultural nonpoint source pollution and particularly the needs of RCWP. Bill Crosswhite has identified models and monitors as both tools and individuals. However defined, models and monitors need to work together in a systems approach. My interpretation of Marshall Jennings' definitions of monitoring and modeling detects a distinction in their use, i.e., a prime purpose of monitoring provides data for trends determination or enforcement (on input to water quality models), whereas modeling is more of a predictive tool. Thus, one could say monitoring is slanted to standards and enforcement, whereas modeling focuses on projections.

These remarks address several of the facets of water quality monitoring, including legislative requirements, information theory, economic principles applied to monitoring, and policy decision making.

Monitoring of water quality can be done 1) for research purposes, 2) to provide data on water quality parameters for whatever purpose, 3) to generate data for regulatory or prescriptive purposes, i.e., to detect violations in water quality as measured against predetermined standards. This paper addresses the third purpose to obtain information to guide policy formulation and decision making.

The need for monitoring information for policy formulation and decision making is a result of the numerous water quality regulations established at local, state, and national levels.

Within the context of agricultural nonpoint source pollution, the focus here is on the monitoring requirements outlined outlined in the rules and regulations of the Rural Clean Water Program.

RCWP Monitoring Requirements

Section 634.50 of the guidelines for the RCWP focus on comprehensive water quality monitoring, evaluation, and analysis. Note that these three functions are lumped together. This section identifies the need to identify representative RCWP project areas for evaluation of water quality improvement and to make projections on a nationwide basis. The primary goal of water quality monitoring, evaluation, and analysis is defined as "to evaluate the overall cost and effectiveness of projects and BMP's to provide information on the impact of the program on improved water quality and for general RCWP Program Management."

The guidelines go on to state that:

- The monitoring, evaluation, and analysis (MEA) are a joint EPA/USDA responsibility.
- That the criteria for use in MEA are to be determined jointly by SCS and EPA.
- That areas selected for detailed analysis are to be representative of agricultural NPS problems.
- That preference is to be given areas with long-term baseline information on land use, hydrologic data, and water quality.
- That monitoring and evaluation is to begin in advance of the installation of BMP's to be able to document statistically existing land use practices and baseline water quality problems.

The regulations go on to specify that as a minimum the plan will contain:

- Chemical and physical water quality monitoring.
- Biological monitoring.
- Appropriate hydrologic data.
- Soils properties and characteristics, topographic information.
- Land use and farm inventory.

Economics plays at least two roles in monitoring; as an evaluation tool and as a decision making tool. As an evaluation tool, economics provides a framework for identifying the least costly method to meet prescribed standards or goals. This cost-effective analysis begs the benefits question. Economics in this context merely identifies the system or practices which give the "biggest bang for the buck" and determines the effectiveness of BMP's. Alternatively, economics can play a role in the establishment of goals or standards through the identification and analysis of the benefits and costs of a variety of levels of water quality. Such analysis would permit marginal analysis by allowing water quality standards to be viewed as variables, rather than basic parameters to be met at all costs. Given concerns over the high costs of meeting certain goals or standards, the estimation of benefits and costs for a range of water quality standards becomes very crucial information.

Monitoring has been generally defined as the systematic collection and evaluation of physical, chemical, biological and other data pertaining to sources of pollution that may influence environmental quality. Cooley has identified important objectives of a water quality monitoring program as:

- To characterize and define trends in the physical, chemical and biological conditions of water.
- To establish baselines of water quality.
- To provide for a continuing assessment of control programs.
- To identify new or existing water quality problems.

Some baseline questions need answering to establish an efficient monitoring program. These are:

- Why conduct the program? — To determine if BMP's are effective and if compliance is occurring.
- Who will conduct the program? — States generally, financed by state and federal funds.
- Where will it be conducted? — Difficult to answer, perhaps both upstream and downstream from allpoint sources, but very expensive. A second approach would be to use network monitoring systems. Yet another would be a modeling approach based on well calibrated models tied to site specific research results.
- When will sampling occur? — Difficult to specify. Monitoring is needed after intense rainfalls as well as large rainfalls, especially during the cultivation period. Suggests need for on-line samples which is very expensive.
- What will be monitored? — Don't use shopping list approach. Rather, select the parameters in relationship to the receiving water body, the surrounding landscape, and the nonpoint pollutants of concern. For example, if emphasis is on control of soil loss, such water quality parameters as turbidity and total dissolved solids are important. This, however, overlooks the nutrient and pesticide aspects. Monitoring also should be geared to special problem areas and not to global situations.

Emphasis on control of agricultural nonpoint pollution places a tremendous burden on the capabilities and resources available for water quality monitoring. In order to use these scarce resources most efficiently, it is necessary that monitoring and measurement activities be combined into an efficient information delivery system.

Monitoring of water quality parameters can be viewed as a production process, with inputs (resources) and outputs. The inputs to this process are measures for monitoring, whether they are sophisticated, mechanical and electrical devices or human workers taking samples. However organized, these resources contribute to the production of a product, which is information describing the state of water under inquiry, and the effectiveness of measures to improve water quality. Resources thus committed need to be organized and used in the most efficient manner in order to provide the needed monitoring information at the lowest cost. Conversely, it is a method for obtaining the most information from a given set of resources allocated to monitoring.

Traditional economic theory tells us that resources would be allocated to monitoring up to the point where the cost of obtaining the information is just equal to the benefits derived from the last increment of information obtained. Just as in the case of determining the costs and benefits of water quality improvement, much more information is known about the costs of monitoring systems than the benefits of monitoring systems. In other words, reams of water quality data are useless without a system for delivering this information to policymakers.

The economics of information deals with the question of selecting that information system from among many which will provide the largest benefit over time.

A general information model can be expressed as:

$$\text{Max: } D = E(g) - E(k)$$

where $E(g)$ is expected gross payoff
and $E(k)$ is expected cost

Important variables to consider in the payoff side of the expanded information model include the process of inquiry, the process of decision making, the probability that certain events will occur once a decision is made, and the benefit function. Variables influencing the expected cost include the processes of inquiry and decision making, the probability of events occurring, the cost of inquiry, and the cost of decision making (Eisgruber).

Monitoring produces data, which is distinct from information. Data must be processed and interpreted through statistical and economic analysis, policy staff and policy evaluation. These interpretative actions transform data into information by placing them in a specific problem context to give meaning to a particular decision.

An information system should contain as a minimum 1) a data system (collection, storing, processing and retrieval) and 2) analytical capabilities to interpret the data (theory, methods).

Control of agricultural NPS pollutants begins with an action taken or refrained from at the farm and more specifically the field level. Measurement of the impact of these actions (or inactions) can begin at the farm level, but stream monitoring usually reflects the aggregated impacts of a number of fields and farms. The challenge to successful monitoring is to be able to identify and measure the relationship between what occurs on all the individual fields and farms in a watershed and the water quality in the streams draining the area. The impacts of combinations or systems of practices rather than individual practices need evaluation.

The agricultural production system combines a variety of inputs to produce food and fiber. Some of the less desirable outputs are the pollutants which degrade water quality and cause economic costs downstream. To examine the impacts of changes in this production system to bring about changes in water quality, one must consider the interactions of important factors, such as land use and applications of chemical fertilizers and pesticides.

The measurement of change in water quality of a particular stream or lake requires data on both water quality and land use before, during, and after the installation of new practices or changes in input use of tillage. Without such a set of data, all one can say is that changes occurred, but without any means for stating why they occurred. It is vital that this data associating land use with benchmark water quality be available.

Moving from the general statements of what would be ideal to the specifics of how to resolve operational problems creates problems. For example, how do you monitor progress in critical areas if problems from specific fields lose their identity as the geographic area enlarges? If there are many critical areas within a watershed, where should monitoring stations be? How does monitoring sort out the effect of certain practices? Or should one realistically expect them to show up? Does one add up the costs of all practices applied in the critical area, measure changes in stream quality, and then devise a rough relationship between total costs and effectiveness? Would this approach differ from costing all the steps necessary to meet certain stream standards?

Numerous examples exist in the economics literature where linear programming analysis has been used to show the economic impact on farms, watersheds, or even larger regions, of having to organize production to meet certain constraints, such as limitations on soil loss, etc. These blanket prescriptions skirt the issue of whether the imposed limitation had any economic justification from a water quality improvement viewpoint. Changes in income and production associated with land use changes or restrictions on input use are typically estimated in such analysis.

Water quality monitoring traditionally measures changes in stream quality, actual or desired. Prescriptive statements are then made about the types of land use changes needed to change stream quality. Economics injects into this discussion the question of what is the cost of achieving the desired level of water quality desired. In order to evaluate the economic impacts, one needs data on the costs in terms of yield and production associated with input changes. Given that the water quality from a farm can be monitored at a single point leaving the farm, what kind of physical data is needed to show the effects of numerous changes in practices applied on the farm?

One approach would be to identify certain standards that must be met at that measurement point for the parameter under investigation, i.e., suspended solids, BOD, N, P, etc., for some period, either storm or average annual basis. Then the farmer, if he had information on the effectiveness of various practices, would organize his resources to maximize his profits subject to the required standards. Needless to say, data voids exist, particularly on the impacts of specific systems of practices on pollutant movement.

A partial list of questions related to economic issues surrounding water quality monitoring includes:

1) What are the parameters for an economic evaluation, and what physical data is needed? For alternative levels of quality measured there are different levels of costs at the farm. These need monitoring also.

2) Is the same monitoring approach valid for both farms and watersheds?

3) What are sensitive economic indicators to measure success for achieving water quality improvement? In other words, do small changes in water quality improvement come at a large cost in farm production and income?

4) What about a combined monitoring and modeling approach? Modeling can identify alternative land treatment options. Economic analysis may suggest use of modeling in the selection of land treatment options and then relate treatment to results.

5) Given a limited budget for monitoring water quality practices, where should the work be done? What criteria should be used for monitoring area selection? What types of monitoring networks can be established?

The research on Black Creek in Indiana offers the following insights on water quality problems.

1) Transport of sediment and nutrients is strongly associated with large storms which occur only a few times during the year.

2) In order to characterize nutrient and sediment loading from small watersheds, runoff from large storm events must be well monitored, and with few exceptions, automated sampling is required.

3) Water quality characteristics vary significantly over short stream distances. This emphasizes the importance of careful selection of monitoring stations for monitoring water quality.

4) The most cost-effective method of achieving improved water quality through the BMP approach is to concentrate remedial efforts on those critical areas within watersheds where maximum benefit can be obtained. This suggests that monitoring systems be designed to concentrate on critical areas. Perhaps modeling can identify where critical areas are and where monitoring activities may be most effective.

5) What are the significant differences between small scale and large scale project

monitoring requirements? At small scale level the relationship between practices and water quality may be measurable. At the large scale level, the effects combine so that individual practice effects are not distinguishable.

6) What constitutes adequate background or benchmark data for measuring progress? What can one say if adequate background data is not available? What is readily available from data bases that are tied to land use and soils?

7) What data are necessary to say anything about program effectiveness? At the field level detailed information on such things as land use, practices, pesticide use, and fertilizer use is necessary, along with soils data.

8) What about expanding the definition of monitoring to include monitoring the economic impact on farmers of selected options, as well as monitoring stream quality?

In summary:

a) Monitoring produces data which must be converted to information before it can be used in any policy or evaluation framework. Cost and benefits must be related for efficient monitoring systems.

b) RCWP regulations combine monitoring, evaluation, and analysis to evaluate overall cost and effectiveness of projects and BMP's to provide information on the impacts of the program on improved water quality.

c) Economics can be used both as an evaluation and as a decision making tool, i.e., in both the evaluation of and establishment of standards.

d) Monitoring needs to include the monitoring of effects on the farm operation and down-stream activities as well as at the point of measurement.

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